BIM-CAREM: A REFERENCE MODEL FOR BUILDING INFORMATION MODELLING CAPABILITY ASSESSMENT

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ABSTRACT

BIM-CAREM: A REFERENCE MODEL FOR BUILDING INFORMATION MODELLING CAPABILITY ASSESSMENT

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Building Information Modelling (BIM) has been implemented by various Architecture, Engineering, Construction and Facilities Management (AEC/FM) firms in various countries due to inefficiencies in traditional construction project management practices. AEC/FM organization require to gauge the effectiveness of their BIM implementations for measuring their performance and enabling continuous improvement in BIM usage. Therefore, various BIM capability and maturity models are developed to help organizations achieving different BIM assessment purposes in AEC/FM industry. Due to the differences in applicability and focus of these models, they meet the demands of different BIM users. Thus, there is no commonly accepted and broadly used BIM capability assessment model in the AEC/FM industry. Furthermore, various types of facility information are generated and used by different stakeholders in different facility life cycle stages. Fragmented structure of construction projects require assessing BIM implementations based on specific processes. Nevertheless, the models in literature, do not enable process based BIM capability assessments. In this study, a reference model for assessing BIM capability of AEC/FM processes, which is called BIM-CAREM, is developed. BIM-CAREM is composed of two parts which are BIM Process Reference Model and BIM Measurement Framework. In the first part, key AEC/FM processes have been determined and defined in terms of process purpose and BIM outcomes. In the second part, BIM capability levels, associated BIM attributes, and a rating scale have been defined to be used during assessments. BIM-CAREM is developed based on the meta-model of ISO/IEC 33000 and later, an iterative development is performed through expert reviews and an exploratory case study. Finally, it is tested in four different firms using multiple case studies method. The results indicate that, BIM-CAREM is capable of covering key processes of facility life cycle and that BIM capability levels and BIM attributes are suitable for identifying BIM capabilities of different processes of organizations at various capability levels.

Keywords: Building Information Modelling (BIM), Capability and Maturity Model, BIM Capability Assessment, BIM Performance

ÖZ

BIM-CAREM: YAPI BİLGİ MODELLEMESİ YETKİNLİK DEĞERLENDİRMESİ İÇİN BİR REFERANS MODEL

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Yapı Bilgi Modellemesi (YBM), inşaat projesi yönetimindeki geleneksel yöntemlerin verimsizlikleri nedeniyle farklı ülkelerdeki çeşitli inşaat firmaları tarafından sıklıkla kullanılmaktadır. Mimarlık, Mühendislik, İnşaat ve Tesis Yönetimi firmaları, YBM kullanım performanslarını ölçmek ve iyileştirmek için mevcut YBM uygulamalarının etkinliğini değerlendirmeye ihtiyaç duyarlar. Bu amaçla, çeşitli YBM yetkinlik ve olgunluk değerlendirme modelleri oluşturulmuştur. Değerlendirme amaçları ve uygulama alanlarındaki farklılıklar nedeni ile bu modeller farklı kullanıcılara hitap etmektedir. Bu nedenle, inşaat sektöründe herkesçe kabul gören ve yaygın olarak kullanılan bir YBM değerlendirme modeli bulunmamaktadır. Ayrıca, inşaat projesi yaşam döngüsünün fazlarında farklı paydaşlar tarafından birçok bilgi üretilmekte ve kullanılmaktadır. İnşaat projelerinin parçalı yapısı, YBM uygulamalarının inşaat süreçleri bazında değerlendirilmesini gerektirir. Ancak, literatürdeki modeller süreç bazlı bir BIM performans değerlendirmesi sağlamamaktadırlar. Bu çalışmada, inşaat süreçlerinin YBM yetkinliklerini değerlendirmek için BIM-CAREM adı verilen bir referans model geliştirilmiştir. BIM-CAREM, YBM Süreçleri Referans Modeli ve YBM Ölçüm Çerçevesi olmak üzere iki bölümden oluşmaktadır. İlk bölümde, tüm tesis yaşam döngüsünü kapsayan önemli Mimarlık, Mühendislik, İnşaat ve İşletme ve Bakım süreçlerinin bir listesi bulunmaktadır. Her süreç, sürecin amacı ve YBM çıktılarına dayanarak tanımlanmaktadır. İkinci bölümde, YBM yetkinlik seviyeleri, ilişkili YBM öznitelikleri ve bir derecelendirme ölçeği tanımlarını içermektedir. Model, ISO/IEC 33000 standardının meta modeli ile uyumlu olarak oluşturulduktan sonra YBM uzmanlarının görüşleri ve bir araştırıcı durum çalışması sonuçları doğrultusunda iki kez güncellenerek geliştirilmiştir. Daha sonra, model nitel araştırma yöntemlerinden birisi olan çoklu durum çalışmaları yöntemi ile dört farklı firmada test edilmiştir. Sonuçlar, modelin tesis yaşam döngüsündeki önemli inşaat süreçlerini kapsadığını ve farklı yetkinlik seviyelerindeki firmaların süreçlerindeki YBM yetkinliklerini tespit edebildiğini göstermektedir.

Anahtar Sözcükler: Yapı Bilgi Modellemesi (YBM), Yetkinlik ve Olgunluk Modeli, YBM Yetkinlik Değerlendirmesi, YBM Performansı

to my father Bekir Yılmaz, mother Kadriye Yılmaz, and

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LIST OF ABBREVIATIONS

AEC/FM	Architecture, Engineering and Construction and Facilities Management
ARCH D	Architectural Design
BIM	Building Information Modeling
BIM A	BIM Attribute
BS D	Building Services Design
C	Construction
CMMI	Capability Maturity Model Integration
CMMI-DEV	Capability Maturity Model Integration for Development
CMMI-SVC	Capability Maturity Model Integration for Services
CMMI-ACQ	Capability Maturity Model Integration for Acquis
FM	Facility Management
GEO D	Geotechnical Design
GP	Generic Practice
GR	Generic Resource
IEC	The International Electrotechnical Commission
ISO	The International Organization for Standardization
MEP	Mechanical, Electrical, and Plumping
MF	Measurement Framework
P	Conceptual Planning
PRM	Process Reference Model
SCAMPI	The Standard CMMI Appraisal Method for Process Improvement
STR D	Structural Design
WP	Work Product

CHAPTER 1

INTRODUCTION

The construction industry is less-integrated than a manufacturing assembly line in other industries such as aircraft and automotive (Smith & Tardif, 2009). Construction projects are so fragmented that different stakeholders such as clients, engineers, end users, service providers, product manufacturers need facility information in various formats in different phases of facility life cycle.

According to the Project Management in Construction of Hendrickson (2008), construction project life cycle composed of seven phases. These are 1 – Perceived Needs, 2 – Conceptual Planning and Feasibility Study, 3 – Design and Engineering, 4 – Procurement and Construction, 5 – Handover, 6 – Operation and Maintenance, and 7 – Disposal of Facility. Throughout the life cycle, various types of data, which are structured, semi-structured and unstructured, and complex information are generated. Some examples of the most important information are (Hendrickson, 2008);

- cash flow and procurement accounts for each organization,
- intermediate analysis results during planning and design,
- design documents, including drawings and specifications,
- construction schedules and cost estimates,
- quality control and assurance records,
- chronological files of project correspondence and memorandum,
- construction field activity and inspection logs,
- legal contracts and regulatory documents.

Most of the facility information is generated in design and engineering phase and is used in the following phases. Without systematic data exchange between stakeholders throughout the facility life cycle, inaccuracies and information loss may occur which cause inefficiency.

Additionally, construction projects involve multiple companies and professionals with different expertise who are working on different tasks. According to Tardif, Murray & Associates Inc. in Quebec, Canada, average number of people and amount information of a $10 million construction project are as follows (Hendrickson, 2008);

- Number of companies: 420 (including all suppliers and sub-sub-contractors)
- Number of individuals: 850
- Number of different types of documents generated: 50
- Number of pages of documents: 56,000
- Number of bankers boxes to hold project documents: 25
- Number of 4 drawers filing cabinets: 6Number of 20 inch diameter, 20-year-old, 50 feet high, trees used to generate this volume of paper: 6
- Equivalent number of Mega Bytes of electronic data to hold this volume of paper: 3,000 MB (scanned)

- Equivalent number of compact discs: 6 (CDs)

Projects' stakeholders take place at different points of facility life cycle for fulfilling their responsibilities. According to RIBA Plan of Work (2013), some examples of project roles are owner, architect, civil and structural engineer, contractor. They need to share various information and communicate frequently which requires collaborative work environment. Starting from information generation in design phase, storing, sharing, coordinating and other manipulation of information, need to be controlled in a collaborative work environment. Especially in design phase architects and engineers need to work in collaboration to eliminate clashes between disciplines such as Architectural, Structural and Electrical, Mechanical and Plumping (MEP). Early collaboration reduces the number of changes which needs to be made in construction phase.

In order to ease collaboration and information sharing between stakeholders, Building Information Modeling (BIM) has been introduced and became important in AEC/FM industry among the world. National Institute of Building Sciences (2015a), defines Building Information Modeling as; "BIM is a business process for generating and leveraging building data to design, construct and operate the building during its lifecycle."

BIM has a significant impact on the efficiency of generating facility information and sharing this information among various stakeholders throughout the facility lifecycle. According to Eastman (2011), benefits of BIM are clustered under four categories which are preconstruction benefits to owner, design benefits, construction and fabrication benefits, and post construction benefit. These benefits are listed in Table1.

Table 1 Benefits of BIM (Adapted from Eastman et al., 2011)

Life cycle phase	**Benefits**
Preconstruction	Increased Building Performance and Quality Improved Collaboration Using Integrated Project Delivery
Design	Earlier and More Accurate Visualizations of a Design Automatic Low-Level Corrections When Changes Are Made to Design Generation of Accurate and Consistent 2D Drawings at Any Stage of the Design Earlier Collaboration of Multiple Design Disciplines Easy Verification of Consistency to the Design Intent Extraction of Cost Estimates during the Design Stage Improvement of Energy Efficiency and Sustainability
Construction and Fabrication	Use of Design Model as Basis for Fabricated Components Quick Reaction to Design Changes Discovery of Design Errors and Omissions before Construction Better Implementation of Lean Construction Techniques Synchronization of Procurement with Design and Construction
Post Construction	Better Management and Operation of Facilities Integration with Facility Operation and Management Systems

Due to these benefits, many initiatives have been undertaken for adopting BIM as an emerging technology in various countries such as the US, the UK, Finland, Norway and The Hong Kong (Edirisinghe, 2012). In these countries, various resources such as BIM guidelines and standards have been created in order to enable BIM standardization and to help AEC/FM organizations for BIM adoption. In 2003, General Services Administration of United States established the National 3D-4D BIM program (GSA, 2003). In 2007, BIM is required for all major projects and GSA BIM guide series are published (GSA, 2007). National BIM Standard's third version is created in 2015 for providing BIM standardization in US construction industry (NBIMS, 2015a). In Finland, BIM is mandated and BIM Requirements are published in 2007 (Senate Properties, 2008). Between 2011 and 2012, Common National BIM Requirements (The Building Information Foundation RTS, 2012), which is called COBIM, is created for defining BIM requirements regarding each phase of facility life cycle. In 2011, UK government mandated the UK construction industry to be at Level 2 BIM maturity by 2016 (Cabinet Office, 2011). BS/PAS 1192 series of standards have been developed for helping UK construction industry to adopt BIM. BIM requirements of Norway are defined in Statsbygg BIM Manual (Statsbygg, 2013) and Civil State Client Statbygg has been using IFC/IFD based BIM since 2010. The Hong Kong Housing Authority has started to piloting BIM in 2006 and more than 19 public rental housing projects have already adopted BIM. In order to support the process, BIM standards, user guides and library component design guides are prepared (Hong Kong HA, 2009c) (Hong Kong HA, 2009b) (Hong Kong HA, 2009a).

Countries, who have made BIM standardization recently, are Singapore and Australia (Edirisinghe, 2012). In Singapore, the Building and Construction Authority implemented the BIM Roadmap in 2010 with the aim of achieving 80% use of BIM in the construction industry by 2015 (BCA Singapore, 2015). In 2012, Singapore BIM Guide (BCA Singapore, 2013) is created for defining national BIM requirements. National BIM Initiative report recommends that the Australian Government set the year of 2016 from which procurement for all its buildings require full collaborative BIM, based on open standards, for information exchange (buildingSMART Australasia, 2012). In 2011, NATSPEC National BIM (NATSPEC, 2011) guide is developed to define nationwide BIM requirements.

Since BIM became mandatory, AEC/FM organizations in these countries needed to adopt BIM in order to be competitive in the industry. However, even though the BIM is not mandatory in some of the countries such as Turkey, AEC/FM organizations are willing to use BIM since they want to take part in international and large-scale construction projects. Additionally, it is a fact that BIM is usually a requirement in large-scale construction projects' contracts in Turkey within the last years. Moreover, companies realize the benefits of using BIM and hence increasingly adopting BIM.

According to one of the surveys of McGraw-Hill construction which is about BIM adoption in North America, industry-wide BIM adoption increased from 28% in 2007 to 71% in 2012. Contractors (74%) have surpassed architects (70%) and engineers (67%) are close to the two other groups (McGraw Hill Construction, 2012a). McGraw-Hill has also looked at BIM adoption rates in Europe and in South Korea. 36% of the European market has adopted BIM in 2010 (McGraw Hill Construction, 2010b) and BIM adoption in South Korea in 2012 is %58 (McGraw Hill Construction, 2012b). According to a recent National BIM report, which highlights the BIM adoption and usage rates within the UK, 54% of the respondents such as Architects, Project Managers, and BIM Managers are aware of and actively using BIM, 42% are aware of BIM and only 4% are unaware of BIM (NBS, 2016).

Successful implementation of BIM requires thorough understanding of existing situations of BIM operations of AEC/FM organizations. Thus, besides the BIM standardization studies, various BIM capability and maturity models are created for gauging the effectiveness of BIM implementations. Models, which are included in the context of this research, are identified through systematic literature review method. Details, and strengths and weaknesses of the models are explained in Chapter 2. Due to the differences in applicability and focus of these models, they meet the demands of different BIM users. Thus, there is no commonly accepted and broadly used BIM capability assessment model in the AEC/FM industry (Wu et al., 2017). Furthermore, various types of facility information are generated and used by different stakeholders in different facility life cycle stages. Fragmented structure of construction projects require assessing BIM implementations based on specific processes. Nevertheless, the models in literature, do not enable process based BIM capability assessments.

The rest of this chapter presents problem statement and motivation, and goals and contributions of the research. And lastly, research questions and research methods are explained.

1.1 Problem Statement and Motivation

Adoption of BIM requires several changes in the AEC/FM organizations, such as aligning business processes to BIM and enabling BIM savvy work force. In order to support AEC/FM organizations to adopt BIM seamlessly and implement it effectively, various resources have been published by governmental organizations of various countries. These guidelines, specifications and standards are developed for helping AEC/FM organizations during the transformation from traditional construction project management practices into BIM integrated project deliveries. Two important and well-known example of these standards are, BS/PAS 1192 series of standards (BSI, 2013)(BSI, 2014b)(BSI, 2015)(BSI, 2007)(BSI, 2014a) which are published by The British Standards Institution, United Kingdom and the National BIM Standard (NBIMS, 2015a) which is published by buildingSMART, United States. BS/PAS 1192, which has five parts, focuses on successful implementation of BIM in different phases and sets out the best practices. The purpose of the National BIM Standard is to support facility life cycle vertically and horizontally by providing means of organizing electronic object data and enhancing communication among all stakeholders associated with the built environment. Details of each standard is presented in Chapter 2. These standards are being used as baseline by many other countries around the world. However, since construction industry have different characteristics specific to different countries, applying these standards in another country's construction industry rather than its origin country might not create the expected results.

Furthermore, AEC/FM organization require to gauge the effectiveness of their BIM implementations in order to measure BIM performance and enable continuous improvement in BIM usage (Wu et al., 2017). Therefore, various BIM capability and maturity models are developed to help organizations achieving different BIM assessment purposes in AEC/FM industry. Eight different BIM capability and maturity assessment models are identified and explained in detail in Chapter 2. There are differences in their applicability and measurement approaches/focuses (Wu et al., 2017). For example, BIM Proficiency Matrix, which is designed by Indiana University, is used to score BIM services performance for selecting designers and contractors on campus building projects. Due to this variety in assessment purposes, users need to examine the models in detail to be able to choose the appropriate model according to their evaluation purposes. Thus, there is not a commonly accepted and broadly used model (Wu et al., 2017).

The models are developed for measuring either projects' or organizations' performances (Giel & McCuen, 2014). They have varying number of metrics which are clustered into different number of layers. On the other hand, they have been developed by inspiring from each other and common concepts have been selected for defining the metrics, because the models are not developed based on established standards. Measures of the models can be clustered basically into two categories namely Organizational and Technical. Organizational category is further divided into sub-categories which are process, stakeholder/personnel, and standard. Technical category is subdivided into three namely software, hardware, and data. Similarly, previous reviews categorized the models' metrics into five categories namely, Process, Technology, Organization, Standard, and Human (Wu et al., 2017, Giel & Issa, 2013). Some example measures for Process category are "clash analysis process", "cross disciplinary model coordination", and "management support" of Multifunctional Maturity Model. Process category's measures are not comprehensive since there are many AEC/FM processes in different facility life cycle stages. Moreover, even though some of the models have included a number of BIM uses in their measures, most of the BIM uses which are performed by AEC/FM organizations are not covered. For example, BIM uses namely, "Quantity takeoffs", "Coordination modelling", "As-Built modelling", and "Asset management" are defined as measures of the model BIM Proficiency Matrix.

Varying number of metrics and number of classification layers are defined in different models. For example, while NBIMS CMM has 11 metrics in total, VDC scorecard has 74 individual measures. Furthermore, NBIMS CMM and VDC Scorecard has 1 layer and 3 layers of classification for their metrics, respectively. The rest of the models have 2 layers of classification for metrics.

Most of the models collect data through online questionnaires which includes quantitative evaluation approaches. Combination of quantitative and qualitative evaluation approaches are required for having more comprehensive evaluations (Wu et al., 2017).

Based on these findings, the limitations of current models are identified as:

- While some of the models only focus on specific assessment purposes, some of them don't have flexible structure,
- There is not a commonly accepted and broadly used model in the literature,
- There is not a model which assesses capability of AEC/FM processes,
- They are not created based on established standards, but inspired from each other,
- Process categories are not comprehensive for covering all facility life cycle phases/processes,
- BIM uses are not comprehensive to cover all BIM uses performed by AEC/FM organizations,

- Most of the models have low or medium coverage of BIM aspects for evaluation due to single or two layers of measures, and

- Most of the models collect data through online questionnaires which include quantitative evaluation approaches.

In addition to the BIM capability and maturity models in construction industry, we also analyzed two well accepted capability and maturity models in software engineering which are Capability and Maturity Model Integration (CMMI) and ISO/IEC 33000 family of standards. Software organizations, who are using these models, are capable of identifying current and potential capability of their own processes and suppliers' processes, and improving their software processes continuously.

CMMI has four different models subject to different areas. These are CMMI for Development (CMMI-DEV) (SEI, 2010b), CMMI for Services (CMMI-SVC) (SEI, 2009a), CMMI for Acquisition (CMMI-ACQ) (SEI, 2010a), and People Capability and Maturity Model (PCMM) (SEI, 2009b).The Standard CMMI Appraisal Method for Process Improvement (SCAMPI) appraisal method is generally accepted for conducting consistent appraisals using CMMI models (SCAMPI Upgrade Team, 2011). In other words, while CMMI –DEV, CMMI-SVC, CMMI ACQ and PCMM are defining related key processes, which are called process areas within the model, and the capability and maturity levels, SCAMPI describes appraisal method for conducting CMMI based appraisals.

ISO/IEC 33000 family of standards has ten parts. ISO/IEC 33001, first part introduces and defines concepts and terms which are used in all parts (ISO/IEC, 2015a) Part 2, 3 and 4 define requirements for performing a process assessment (ISO/IEC, 2015b), requirements for developing process measurement framework (ISO/IEC, 2015c), and requirements for developing process reference model, process assessment and maturity models (ISO/IEC, 2015d), respectively. These three parts explain the requirements and rules for developing process reference model, measurement framework, process assessment and maturity models for the users who want to use ISO/IEC 33000 basis for the development of a new model. There is trend of adapting ISO/IEC 33000 into different domains. Last three parts, which have part number 52, 63, 71 and 72 are process reference model for information security management (ISO/IEC, 2016a), and process assessment model for software testing (ISO/IEC, 2015f), process assessment model for enterprise processes (ISO/IEC, 2016b) and process assessment model for information security management (ISO/IEC, 2016c), respectively. Part number 14 and 20, define the process measurement framework (ISO/IEC, 2013), and guideline for using process assessment results and creating process improvement road maps (ISO/IEC, 2015), respectively.

When we analyzed these two models in detail, it has been identified that they have well-defined structure which is composed of four common parts. These are;

- Process reference model,

- Process measurement framework,

- Documented procedures and requirements for conducting process assessments, and

- Process improvement method.

Each part serves for different purpose but, they are used together. In process reference model a list of key processes are given and definition for each process is provided. In process measurement framework a schema for use in assessing process quality characteristics of an implemented process is presented. And lastly, how to conduct process improvement is defined in process improvement method. Separation of components create values for assessors. These are:

- Process reference model gives opportunity to define priorities for software process assessment and improvement,
- Measurement framework allows to acknowledge the dependencies among outcomes of a process,
- Requirements for process assessments explain appraisal procedures for conducting formal assessments, and
- Process improvement method helps to define road map for process improvement.

When structure of existing models in construction industry is compared to the model structures in software engineering, it has been identified that the models in construction industry do not include;

- A process reference model which includes a list of key processes of a facility life cycle and detailed definitions of these processes in terms of BIM outcomes,
- A measurement framework which formalizes and enables BIM capability assessment of AEC/FM organizations' processes.

Due to the highly-fragmented structure of construction industry, creation, collection, sharing and usage of information are performed by different stakeholders/organizations in each facility life cycle stage. Therefore, AEC/FM organizations need to assess their own BIM capability for each specific process. For example, while design firms need to evaluate BIM capability of their design processes, general contractors may need to assess BIM capability of all AEC/FM processes. A well-structured BIM capability assessment model conformant to the principles of ISO/IEC 33000 standard have a potential to enable process based BIM capability assessments and meet the different users' assessment requirements. Furthermore, this assessment could enable selection of sub-contractors with required BIM capability levels.

Structured model for evaluating AEC/FM processes, including a process reference model and measurement framework, provides holistic approach for covering AEC/FM processes of all facility life cycle stages and enables continuous improvement by allowing users to make multiple evaluations for the same process, and enabling systematic appraisals and benchmarking. BIM users can choose to compare BIM capabilities of specific processes within the organization and/or across the organizations and create BIM improvement paths in terms of their priorities. It also allows users to understand the whole approach easier and implement it partially or fully.

More generally, measurement reliability is increased, since theoretical development of BIM-CAREM is grounded on the meta-model of ISO/IEC 33000 standard, later and updated iteratively via expert reviews and an exploratory case study, and tested with multiple case studies.

1.2 Goals and Contributions of the Research

In order to eliminate the defined limitations, it is aimed to develop a new reference model for assessing BIM capabilities of AEC/FM processes. For development of the model, ISO/IEC 33000 family of standards is chosen as a basis, since requirements for developing process reference model and measurement framework are explained in detail within the parts ISO/IEC 33004 (ISO/IEC, 2015) and ISO/IEC 33003 (ISO/IEC, 2015c), respectively. Similar to the model structures in software engineering, our objectives are to develop two model parts which are;

- Building PRM and BIM PRM,
- BIM MF.

In order to develop first part which is Building PRM and BIM PRM, we have three goals. These are:

1. Identifying key AEC/FM processes which cover all facility life cycle stages,
2. Determining BIM related AEC/FM processes, and
3. Defining each process in terms of process purpose and BIM outcomes,

In order to develop the second part, which is BIM MF, three goals are set. These are:

1. Identifying and defining BIM capability levels and associated BIM attributes which enable process based formal and systematic assessments,
2. Defining observable and assessable results of achieving the BIM attributes which are BIM attribute outcomes, and
3. Defining sources of objective evidences which are Generic BIM Practice, Generic BIM Work Products and Generic Resources.

The scope of the study includes development of a process based BIM capability assessment model and application of the model in the AEC/FM industry in Turkey. Testing the model includes each facility life cycle phase which are conceptual planning, design, construction and facilities management.

The contributions of this PhD dissertation can be classified under two categories as theoretical and practical contribution. Theoretical contribution is to fill the gap in the literature by enabling formal and systematic BIM capability assessment of AEC/FM organizations based on their processes. Practical contribution is to help AEC/FM organizations to be aware of the BIM capabilities of their processes for possibly creating improvement paths in terms of BIM usage.

In this PhD research, it is assumed that testing the model in one company providing services for each facility life cycle phase, which are conceptual development, design, construction and facility management, for different type and sizes of projects, would be representative of the usage in real life.

1.3 Research Questions

As part of this research study, we aim to develop a BIM process reference model. For fulfilling the three goals related to this model development, research question RQ1 and its sub questions RQ1.1 and RQ1.2 needed to be addressed. As we also aim to develop a BIM measurement framework, the three goals related to this development needed to be addressed with research question RQ2 and its sub questions RQ2.1 and RQ2.2.

RQ1: How can BIM processes of a AEC/FM organization be formally assessed?

RQ1.1: What are the key processes that should be assessed for covering all facility life cycle phases?

RQ1.2: What BIM practices and outcomes should be available for each process of facility life cycle?

RQ2: How general can a formalized assessment approach be for assessing BIM capability of AEC/FM organizations?

RQ2.1: What can be the assessment levels of BIM capability and BIM attributes for gauging/evaluating BIM capability of AEC/FM organizations' processes?

RQ2.2: How suitable is the BIM-CAREM to be used for the purpose of identifying AEC/FM organizations' processes capability?

Research questions, their validation methods and validation metrics are explained in detail below.

<u>RQ1: How can BIM processes of a AEC/FM organization be formally assessed?</u>

It is aimed to develop a Building PRM and BIM PRM by answering RQ1 and its sub questions RQ1.1 and RQ1.2. Facility life cycle stages are determined based on the RIBA Plan of Work (RIBA, 2013). BIM process reference model includes process definitions of all facility life cycle stages which are 1-Conceptual Planning, 2-Design, 3-Construction and 4-Facility Management. Therefore, our validation metric is coverage and it is validated through expert reviews and an exploratory case study.

<u>RQ 1.1 What are the key processes that should be assessed for covering all facility life cycle phases?</u>

As explained in section 1.1, according to the ISO/IEC 33004(ISO/IEC, 2015d), a well-defined process reference model has a list of key processes within the related domain. Therefore, it is important to identify the important key processes of AEC/FM organizations' processes.

RQ1.2 What BIM practices and outcomes should be available for each process of facility life cycle?

According to the ISO/IEC 33004 (ISO/IEC, 2015d), processes are defined in terms of process purpose and process outcomes. In order to conduct formal BIM capability assessments, it is required to define the process purpose and observable BIM practices and BIM outcomes of each process.

RQ2 How general can a formalized assessment approach be for assessing BIM capability of AEC/FM organizations?

It is aimed to develop a BIM Measurement Framework by answering RQ2 as well as testing the complete model in representative companies in the AEC/FM industry. By this way, we aim to validate the generality of the approach for enabling assessment of different levels of BIM capability at different organizations.

RQ2.1 What can be the assessment levels of BIM capability and BIM attributes for gauging/evaluating BIM capability of AEC/FM organizations' processes?

As explained in section 1.1, according to ISO/IEC 33003, a well-defined BIM capability assessment model should include a BIM measurement framework which includes a schema for use in assessing BIM capability of an implemented process. Within this schema, it is important to define BIM capability levels, BIM attributes and their observable results, which are BIM attribute outcomes, for allowing formal BIM capability assessments of building processes. Validation of the model is established by expert reviews and an exploratory case study.

RQ2.2 How suitable is the BIM-CAREM to be used for the purpose of identifying AEC/FM organizations' BIM processes capability?

It is important to test the model empirically for identifying how suitable the model is for determining BIM capabilities of AEC/FM organizations' processes. Thus, a multiple case study is conducted in several AEC/FM organizations in Turkey. The validation is established by selecting different firms such as architectural design firms and construction firms, different processes such as architectural detail design and construction, and lastly different project types such as metro projects and sport facilities with reinforced concrete and steel frames. Therefore, our validation metric is the generality of the model.

1.4 Research Methods

Our main research method is qualitative research and flow of our research is presented in Figure 1. First of all, systematic literature review is conducted to identify and analyze existing BIM capability and maturity models and well-known capability and maturity models in software engineering. Analysis results are used for defining literature gap clearly. Conceptual BIM-CAREM, which is the output of step 2 in Figure 1, is developed based on the principles of ISO/IEC 33000 family of standards and the required resources which are identified from literature. Results of natural language analysis on BIM uses are also used for the first version of BIM-CAREM which is depicted in Figure 1. Research questions RQ1 and RQ2 and their sub questions RQ 1.1, RQ1.2 and RQ2.1 are answered by carrying out steps 1 and 2 in Figure 1.

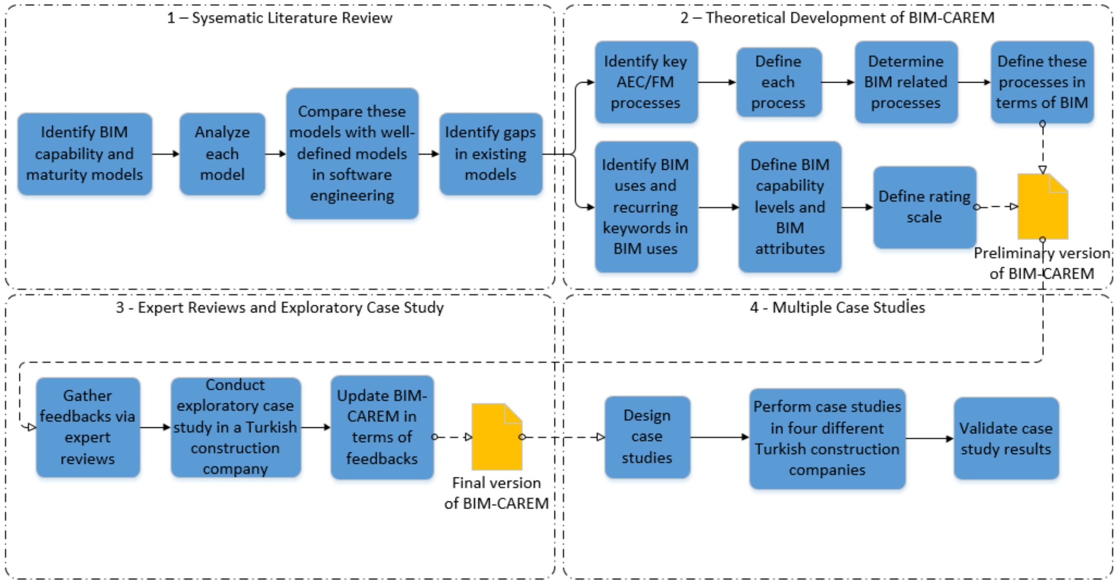

Figure 1 Research methodology

Before testing the proposed model in real life, expert reviews and an exploratory case study is conducted for improving the model iteratively. Expert review is conducted to gather feedbacks about preliminary version of BIM-CAREM. We conducted exploratory case study for capturing if the defined BIM capability levels and the BIM attributes of BIM-CAREM are sufficiently representing AEC/FM organizations at different capability levels. According to Yin (2003) and Fellows (2015), exploratory case study begins with a theory and used for discovering and capturing the factors and measures of the theories and/or models. To test BIM-CAREM in Turkish construction industry, multiple case studies are conducted. According to Yin (2003), case study is an empirical investigation of a contemporary phenomenon within its real-life context. Therefore, multiple case studies helped to collect empirical evidence about suitability of BIM-CAREM for assessing BIM capabilities of AEC/FM processes. Research question RQ2 and its sub question RQ2.2 is answered by carrying out steps 3 and 4 which are presented in Figure 1.

In order to improve the rigor of qualitative research and eliminate the threats to validity, generalizability, and reliability, some technical fixes are performed. Validity, denotes to what extent the case study results are true (Wohlin et al., 2012). Generalizability, is the ability to transfer a set of results from a particular group to a larger group (Fellows & Liu, 2015). Reliability, refers to what happens if a study is carried out again by following the same procedures (Fellows & Liu, 2015). In order to address problems of validity, triangulation, respondent validation, and expert review techniques are being used. Triangulation, is using one or more approaches for data collection, sources of data and data analysis (Fellows & Liu, 2015). We collected primary data from semi structured and face to face interviews with one or more interviewees per organization. Secondary data is collected through direct observations. Direct observations are performed for examining the Generic BIM Work Products such as models developed via BIM tools and clash detection reports and Generic Resources such as software and hardware infrastructure of organizations. Respondent validation, is eliminating problems regarding to accuracy of the investigator's inferences based on the interview (Yin, 2003). For each appraisal, informal checks are conducted. We shared the findings and understandings of each case study with the interviewees for clarification. Furthermore, online questionnaires are applied to each interviewee for validating case study findings. Problems of generalizability is being addressed by sampling (Yin, 2003). A wide range of companies with different focuses such as design firms and construction firms, different sizes and various project types such as airports and metro tunnels, and two frame types such as reinforced concrete and steel projects are selected as samples. Reliability is being addressed with replication of a case study (Yin, 2003) (Fellows & Liu, 2015). We have visited Company B after the case study and important interview questions are asked again.

1.5 Dissertation Organization

The rest of the dissertation is divided into five chapters. Chapter 2 presents the literature review in which gap analysis is emphasized based on analysis of existing capability and maturity models both in software engineering and in construction industry. Chapter 3 introduces the BIM-CAREM and its development process. Proposed model is tested by a multiple case study which is described in Chapter 4. And lastly, conclusions and future work directions are explained in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

This chapter consists of three sections. The section 2.1 presents two well-known national BIM standardization studies, section 2.2 presents the existing BIM capability and maturity assessment models in AEC/FM industry which are investigated by a systematic literature review. Section 2.3 introduces two well-known capability and maturity models in software engineering, and lastly in section 2.4 ISO/IEC 33000 family of standards is explained in detail.

2.1 National BIM Standardization Studies

In this section two national BIM standards are explained in detail since they are widely accepted around the world and are taken as basis for publishing new standards by countries who are recent adopters of BIM. These are BS/PAS 1192 series of standards which is published by The British Standards Institution, United Kingdom and the National BIM Standard which is published by buildingSMART, United States.

In 2011, BIM Maturity Levels is developed by BIM Industry Working Group. A strategy paper is published to announce the BIM maturity levels and their definitions within UK. Although this is not an assessment model for BIM maturity and capability of AEC/FM organizations, it serves as a guideline for BIM learning over period of time. Four BIM maturity levels are defined by grouping building information types such as 2D drawings and 3D models, tools and BS/PAS standards. In Figure 2 simplified version of the UK’s BIM maturity levels are presented (BIM Industry Working Group, 2011).

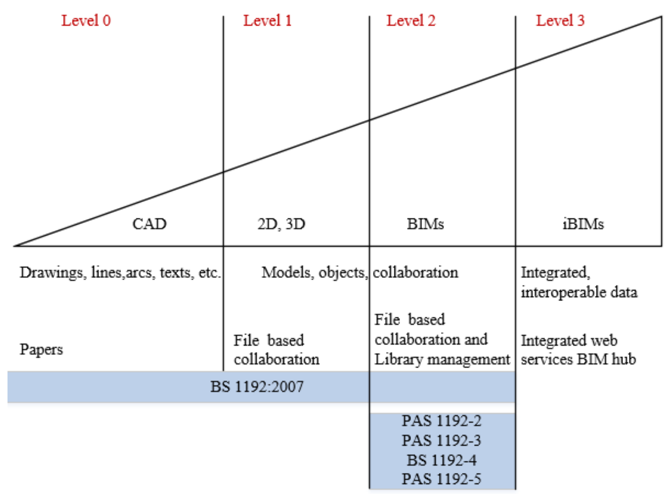

Figure 2 UK's BIM Maturity Levels (BIM Industry Working Group, 2011)

AEC/FM organizations at Level 0, exchange 2D CAD data based on paper (or electronic paper). At Level 1, managed 2D or 3D CAD data is exchanged based on common data environments with standard data structured and formats by using BS 1192-2007. At Level 2, managed 3D building information is held in different models for different disciplines. Integration is established by proprietary and interoperable formats. Additionally, phase and 4D planning and 5D cost estimating is conducted based on the model. At Level 3, data integration is enabled by web services. IFC/IFD interoperable data formats are used and managed by a collaborative model server and fully open process and data integration is enabled (BIM Industry Working Group, 2011).

Achieving these maturity levels are supported by a series of standards which are created by the British Standards Institution. There are five parts of PAS 1192 which are as follows;

- BS 1192:2007 introduces a collaboration methodology for managing the production, distribution and quality of building information. This code of practice allows architects, engineers and constructors to create a collaborative environment which supports communication, re-use and share data efficiently without loss, contradiction or misinterpretation. Basically, the standard describes creating a Common Data Environment (CDE) which allows users to create, share, publish, and archive information in a systematic approach. It introduces and explains the rules and procedures how to use and manage the CDE systematically and includes naming conventions of files and folders, etc. (BSI, 2007).

- PAS 1192-2 explains requirements of information management for achieving UK's BIM Level 2 in the capital/delivery phase of construction projects. The standard starts explaining the contents of the Employer's Information Requirements (EIR). EIR document should contain detailed information about information management, commercial management and competence management. After gathering the EIR in detail, procurement which is contract selection process should be followed. For selecting the suppliers, BIM execution plan, Project implementation plan and Supplier BIM assessment form should be created, respectively (BSI, 2013).

- PAS 1192-3 specifies requirements of information management for achieving UK's BIM Level 2 regarding operation and maintenance of assets. This standard explains how Asset Information Model (AIM) is built for the owners and operators of assets for the operation and maintenance stages. It describes transferring information from Project Information Model (PIM) to the AIM and how a digital AIM is created for an existing asset (BSI, 2014b).

- BS 1192-4 defines information exchange by using COBie throughout facility life cycle in UK's construction industry. It suggests that COBie information should be kept and maintained for Portfolio, Asset and Facility Management and Operational Management. It defines validity, consistency parameters of the COBie template. Lastly, implementation of COBie is explained by giving an example (BSI, 2014a).

- PAS 1192-5 introduces a security framework which guides asset owners and project stakeholders in understanding vulnerabilities and security issues of digital built environment (BSI, 2015).

The purpose of the National BIM Standard is to support facility life cycle vertically and horizontally by providing means of organizing electronic object data and enhancing communication among all stakeholders associated with the built environment. It introduces a high variety of concepts related to BIM which are categorized into three main groups;

- Reference standards includes a set of standards which are ISO 16739, Industry Foundation Class 2X3 – February 2006, W3C XML 1.0 Fifth Edition – November 2008, OmniClass, International framework for dictionaries, BIM collaboration format, LOD specifications and lastly, United States CAD standard (NBIMS, 2015d),

- Information exchange standards includes a set of standards which are COBie, Design to spatial validation program, Design to building energy analysis, Design to quantity take off for cost estimating, Building programming information exchange, Electrical information exchange, Heating, ventilation, and air conditioning information exchange, and Water systems information exchange (NBIMS, 2015b),

- Practice documents are Minimum BIM, BIM project execution planning guide, BIM project execution plan content, Mechanical, electrical, plumbing and fire protection systems spatial coordination requirements for construction installation models and deliverables, Planning, executing and managing information handover, BIM planning guide for facility owners, Practical BIM contract requirements and The uses of BIM (NBIMS, 2015c).

2.2 BIM Capability and Maturity Assessment Models in Construction Industry

This research study has begun with identifying existing BIM capability and maturity models. In the systematic literature review paper of Yilmaz et. al. (2017) a total number of 189 papers are investigated through databases and manual search, 84 of which are found relevant. After examining these articles in detail, 6 BIM capability and maturity assessment models and 1 process improvement framework for facility management processes, which is called SPICE FM, are determined, analyzed and explained in detail. Besides these seven models, 2 recent BIM assessment models are identified and included in the context of this PhD research. In total, 8 BIM capability and maturity models and SPICE FM which does not have BIM aspect is selected and explained in detail this section.

2.2.1 *NBIMS BIM Capability Maturity Model*

The first BIM maturity assessment tool is BIM Capability Maturity Model (CMM) which is defined by National Institute of Building Sciences as part of the its well-known standard National BIM Standard (NBIMS). It is created for AEC/FM industry to be used for evaluating business practices of construction projects along a desired BIM maturity. There are two versions of BIM CMM which are tabular BIM and interactive BIM. The Tabular CMM is in matrix format with 11 areas of interest assessed against 10 maturity levels. Interactive CMM has the same information as the tabular form, but it is in excel format. BIM maturity is calculated based on the points for maturity against 11 categories which are given with their definitions as follows (NBIMS, 2015e);

- Data richness, identifies the completeness of the building information model from initial data to corporate facility information.

- Life cycle view, identifies how many facility life cycle phases are covered by BIM.

- Roles or disciplines, refers to the stakeholders of the business processes and its information flows.

- Change management, identifies methodology used to for root cause analysis of the problem and changing the business processes.

- Business process, identifies how data and information is gathered for accomplishing the business.

- Timeliness/response, identifies how close facility information to real time data and determines its update rate.

- Delivery method, identifies how facility information is shared.

- Graphical information, determines what the graphical information detail is.

- Spatial capability, determines whether facility elements have spatial understanding.

- Information accuracy, identifies whether there are mathematical ground truth products.

- Interoperability/IFC support, identifies whether interoperable formats are used.

Each category has description and points against 10 maturity levels. By looking at these descriptions, users can determine at which level the category is. Final BIM maturity is weighted sum of all category points. In version three of the National BIM Standard, concept of Minimum BIM is defined. If the total score is not equal to the points of minimum BIM, then it is not called BIM. In order to improve BIM maturity, steps to be followed are summarized in the standard (NBIMS, 2015e).

2.2.2 *BIM Proficiency Matrix*

Later, BIM Proficiency Matrix, which is designed by Indiana University for selecting designers and contractors on campus building projects. It is used to score BIM services performance in terms of 8 areas and each of which has 4 measures as follows (IU Arhictect's Office, 2009):

- Physical accuracy of the model (Basic model geometry, design requirements, design side collision detection, and model accuracy),

- Integrated project delivery methodology (Creation of a BEP, introduction of structural and MEP model, model managers' role defined, and IPD methodology innovation)

- Calculation mentality (Basic model information export, IPD integration, interdisciplinary calculations, and calculations innovation),

- Location awareness (Site orientation, existing environment awareness, global accuracy, and location innovation),

- Content creation (Geometrically correct content, manufacturer's specific, design intent, and content innovation),

- Construction data (Quantity takeoffs, object scheduling, material procurement, and construction innovation),

- As-Built modelling (Post bid model documentation, coordination modeling, recapturing design intent, and As-Built innovation), and

- FM data richness (Space management data, asset management, manufacturer specific information, and FM data innovation).

The tool is in excel format and categories can be scored either 1 or 0 based on their existence or not. Final BIM maturity score is sum of all areas' scores. This score helps to identify the maturity level of the BIM services. Matrix defines 5 levels of BIM maturity as Working towards BIM (BIM score between 0-12), Certified BIM (BIM score between 13-18), Silver (BIM score between 19-24), Gold (BIM score between 25-28), and Ideal (BIM score between 29-32) (IU Arhictect's Office, 2009).

2.2.3 *BIM Maturity Matrix*

One of the most cited model for assessing BIM capability and maturity is BIM Maturity Matrix which is a framework for assessing individual and team BIM competency, organizational capability and maturity and project BIM performance.

BIM Maturity matrix has five metrics for BIM performance measurement. These five components are BIM capability stages, BIM maturity levels, BIM competency sets, organizational scale and granularity level. BIM competency sets are technology (software, hardware and data/networks), process (resources, activities/workflows, products/services, and leadership/management) and policy (benchmarks/controls, contracts/agreements and guidance/supervision). Organizations has three scales: macro (markets and industries), meso (project teams), and micro (organizations). Granularity levels of assessment are discovery, evaluation, certification and auditing (Succar, Sher, & Williams, 2012). BIM capability stages contains three values which are object based modelling, model based collaboration, and network based integration. BIM maturity levels are defined as a) ad-hoc, b) defined, c) managed, d) integrated and e) optimized. Each level is given a constant maturity point as Level a, b, c, d, and e for 10, 20, 30, 40 and 50 points, respectively (Succar, 2010).

The first two steps of assessments are selection of organizational scale and granularity level. These two selection reduce the number of applicable competencies. As the third step, capability stage is determined. Competency sets are assessed based on the five maturity levels. Each competency is given a maturity level which is assigned to a maturity point. In order to calculate the maturity discovery score, the average of total points is divided by the number of competencies, one capability stage and one organizational scale (Succar, 2010) (Succar et al., 2012). BIM Excellence (BIMe) is a commercial online platform which includes multiple modules for performance assessment of individuals, organizations projects and teams. It is based on the Succar's BIM Maturity Matrix and free online assessment creates BIM maturity assessment reports according to the scores which users give between 0 (none) to 4 (expert) for survey questions (BIM Excellence, 2013).

2.2.4 *BIM QuickScan*

BIM QuickScan is created for benchmarking BIM performance in the Netherlands. It consists of an online questionnaire with almost 50 questions grouped under 4 categories which are organization and management, mentality and culture, information structure and information flow, tools and applications. Total score is the weighted sum of all categories points. Resulting BIM level provides insight about BIM strengths and weaknesses of the construction organization. BIM level of an organization ranges from 0 to 5. BIM QuickScan allows two versions of scan self-scan and expert scan (Berlo et al., 2012) .

2.2.5 *Virtual Design and Construction Scorecard*

Virtual Design and Construction (VDC) Scorecard is developed by Stanford University and measures the project performance against an industry benchmark. It includes 4 major areas, 10 divisions and 74 measures. Four major areas are 1-Planning, 2-Adoption, 3-Technology and 4-Performance. Planning area establishes the quantitative and qualitative project objectives and to identify standards, technologies, and resources for the project. Technology area evaluates the models by assessing maturity of model uses, LOD of models and model integration success. Adoption area assesses the processes by evaluating the success in aligning stakeholders' talents, motivations, incentives, and business structures. Performance area assesses the achievement of project objectives. These areas are divided into ten divisions and ten divisions are evaluated by 56 metrics (Kam et al., 2013). Divisions and critical measurement points of each area are given in Table 2.

Table 2 VDC Scorecard's divisions and measurement points of each area (Kam et al., 2013)

Area	**Division**	**Measurement Points**
1	Objective	Stakeholder formalization, Management objective, Quantifiable objectives, Objective categories, Stakeholder benefits
	Standard	VDC guidelines, BEP/VDC guides, VDC development
	Preparation	Project interaction mode, Project interaction coverage, Data sharing, VDC budget, VDC software
2	Organization	Stakeholder motivation, VDC skill, VDC training frequency, VDC training coverage, VDC staff participation, FTE percentage, Stakeholder involvement, VDC experience, Designated BIM specialist, Stakeholder attitude, Stakeholder action, BIM infusion
	Process	Project benefit, VDC application, Project delivery, Efficiency, RFI response, Process improvement
3	Maturity	Level of application
	Coverage	3D elements, LOD support
	Integration	Model exchange format, Interoperability, Average LOD, LOD adequacy, Software adequacy, Hardware adequacy, Business loss impact, Stakeholder application, Member application, Customer communication
4	Quantitative	Objective tracking, Performance measurement, Planning and modelling alignment, RFI expectation, Unforeseen order change, Field-initiated order change, Target achievement, Target maturity

	Qualitative	Performance assessment, Model assessment, Satisfaction and importance, User satisfaction

Area scores are calculated by weighted sum of division scores, and overall VDC score is calculated by weighted sum of area scores. VDC score is based on percentage scale and reflects the project performance relative to a benchmark which consists of 150 pilot projects' VDC scores (Kam et al., 2013). bimSCORE is a commercial tool and a decision dashboard which uses the VDC Scorecard as baseline. It provides organizations the ability to evaluate their BIM maturity, to benchmark their BIM projects, and to advice BIM decision making and investments. Same BIM evaluation methodology is used with the VDC Scorecard (Strategic Building Innovation, 2013).

2.2.6 *Organizational BIM Assessment Profile*

Organizational BIM Assessment Profile is a matrix defined within the context of Facility Owner's Guide by Penn State University. It is used to evaluate the organization's maturity of BIM planning elements. Those elements are defined as 1-BIM strategy, 2-BIM uses, 3-Process, 4-Information, 5-Infrastructure, and 6-Personnel. Each planning element has sub elements. These sub elements are presented in Table 3.

Table 3 Organizational BIM Assessment Profile's BIM planning sub elements (PennState CIC, 2013)

BIM Planning Element	**Sub Elements**
1	Organizational mission and goals, BIM vision and objectives, management support, BIM champion, and BIM planning committee
2	Project uses and operational uses
3	Project processes and organizational processes
4	Model Element Breakdown (MEB), Level of Development (LOD) and facility data
5	Software, hardware and physical spaces
6	Roles and responsibilities, organizational hierarchy, education, training and change readiness

Those six planning elements have 20 sub-elements in total. The assessment matrix defines 6 maturity levels, these maturity levels are L0-Non Existent, L1-Initial, L2-Managed, L3-Defined, L4-Quantitatively Managed and L5-Optimizing. Each sub element has definitions in terms of maturity levels and takes scores against maturity levels. If a sub element such as management support is at L3-Defined, its score becomes 3. Overall maturity level is equal to weighted sum of all sub elements' scores (PennState CIC, 2013).

2.2.7 *VICO BIM Scorecard*

In 2011, BIM software tool vendor VICO, which is recently became of Trimble, has developed a BIM Scorecard. The evaluation process is conducted based on 7 categories which are portfolio and project management, cost planning, cost control, schedule planning, production control, coordination and design team engagement. Each category has 3 questions which covers software solutions, best practices and integrated processes. Measurement tool has 21 questions in total in the form of online questionnaire. Total score is weighted sum of 21 questionnaire questions. 4 levels of capability, which are 0-No Capability, 1-Low Capability, 2-Satisfactory Capability and 3-High Capability, are defined. (VICO Software, 2011).

2.2.8 *Multifunctional BIM Maturity Model*

A recent research is conducted to develop a multifunctional BIM Maturity Model which is used to evaluate BIM maturity in projects, companies with a portfolio of projects, and the industry as a whole. This model contains 3 domains which are technology, process, and protocol. Each domain has 7 subdomains which makes 21 measures in total. Subdomains of Technology are information accuracy, model data, quality assurance & control, data security & saving, technology infrastructure & needs, BIM elements, and spatial & coordination. Process domain contains the subdomains; clash analysis process, data exchange, CAD/BIM workflow, cross-disciplinary model coordination, delivery method, BIM project objective, and management support. Protocol domain includes the subdomains; interoperability/IFC support, project deliverables, doc & modelling standards, standard operating process, role & responsibility, compensation expectations, and BIM & facility data requirements. Model defines 4 levels of maturity. Subdomains are assessed against maturity levels and they are weighted equally to calculate the overall maturity score (Liang et al., 2016).

2.2.9 *SPICE FM*

Structured Process Improvement for Construction Enterprises (SPICE) is a process assessment framework for AEC/FM organizations. Although it does not measure BIM aspect of organizations, it is included in the context of this study since it is the only model which enables construction process assessment. Weaknesses and strengths of key processes are identified to derive improvement suggestions. It has 5 maturity levels which are L1-Initial, L2-Repeatable, L3-Defined, L4-Managed, and L5-Optimising. A number of key processes are defined regarding each maturity levels. These key processes, which are given in Table 4 (Sarshar et al., 2004), are assessed against 5 process enablers which are commitment, ability, verification, evaluation, and activities (Sarshar et al., 2000).

Table 4 SPICE key processes of each maturity level (Amaratunga et al., 2002)

Levels	SPICE Key Processes
1	There are no key processes.
2	Brief and scope of work management, project planning, project tracking and monitoring, subcontract management, project change management, health and safety management, risk management, project team co-ordination.
3	Organization process definition, organization process focus, integrated design and construction management, construction lifecycle engineering, training program, peer reviews.
4	Quality management, quantitative process management.
5	Process change management, technology change management, defect prevention.

Later, SPICE approach is adapted into FM by defining FM key processes for each maturity level. The SPICE FM framework specifically focuses on FM for improving FM processes. SPICE FM includes 5 maturity levels which are L1-Initial, L2-Service Delivery Management, L3-Knowledge Management, L4-Quantitatively controlled, L5-Continuously Improving, and key processes are defined for each level (Construct IT, 2001) (Amaratunga et al., 2002). Maturity level of an FM organization is decided based on the evaluation of key processes against defined 5 process enablers. To create continuous improvement, framework has three stages which are determining strategic targets, assessing existing FM management procedures, and implementing and monitoring (Construct IT, 2001). SPICE FM framework is not included in the comparison table of Table 5, but it is utilized for the development of BIM-CAREM.

2.2.10 *Limitations of BIM Capability and Maturity Models*

8 models, which are NBIMS CMM, BIM Proficiency Matrix of Indiana University, BIM Quick Scan, VDC Scorecard, Organizational BIM Assessment Profile, VICO BIM Scorecard, BIM Maturity Matrix and Multifunctional BIM Maturity Model (M-BIM MM), are compared in terms of five criteria and results are presented in a comparison table (Table 5). These five criteria are as follows:

- Measurement scope and purpose: A BIM capability and maturity model have to be flexible or have to enable performing assessments for different BIM assessment purposes

- Selection and classification of metrics: A BIM capability and maturity model have to include comprehensive measures by covering BIM aspects/uses of AEC/FM industry,

- Evaluation approaches: A BIM capability and maturity model have to include the components which are BIM capability levels, associated attributes/measures and a rating scale. It shall enable both qualitative and quantitative evaluation approaches,

- Validation method: A BIM capability and maturity model have to be validated via multiple validation methods such as expert reviews and pilot project testing, and

- User support: A BIM capability and maturity model have to include benchmarking and user guideline support.

<u>Measurement scope and purpose:</u> Previous research studies have clustered the BIM capability and maturity assessment models into two categories as project evaluation and organization evaluation (Giel & McCuen, 2014). For example, while NBIMS MM and VDC Scorecard focus on evaluating BIM maturity of construction projects, BIM Proficiency Matrix, BIM Quick Scan, Organizational BIM Assessment Profile, VICO BIM Scorecard, BIM MM, Multifunctional BIM MM assess BIM maturity of AEC/FM organizations. Only SPICE FM (Amaratunga et al., 2002) focuses on assessing maturities of facilities management processes, but it does not measure BIM maturity. In conclusion, there is not a model which enables process based BIM capability and maturity assessment of AEC/FM organizations.

Each model has been developed for achieving a specific BIM assessment purpose. For example, the first developed model, NBIMS CMM is for assessing BIM maturity of business practices of construction projects. BIM Proficiency Matrix, which is designed for selecting designers and contractors on campus building projects, is used to score BIM services performance. Organizational BIM Assessment Profile is developed to evaluate the organization's maturity of BIM planning elements. Due to the variation of models’ applicability and focus, users need to examine the models in detail to be able to choose the appropriate model according to their evaluation purposes (Wu et al., 2017). Therefore, there is no commonly accepted and broadly used model in the literature.

Selection and classification of metrics*:* Varying number of metrics and number of classification layers are defined in different models. While NBIMS CMM has 11 metrics in total, VDC scorecard has 74 individual measures. Furthermore, while NBIMS CMM and VDC Scorecard has 1 layer and 3 layers of classification for metrics, respectively, the rest of the models have 2 layers of classification for metrics. NBIMS CMM has the simplest structure among all tools, so that it is easy to use. However, it is criticized for having single evaluation method (Wu et al., 2017). Thus, having 2 or 3 layers increases coverage of BIM aspects.

Although each model has different number of measures which are clustered into different numbers of layers, common concepts have been selected for defining the metrics. Most of the models classified their measures into common categories which process, stakeholder/personnel, standard, software, hardware and data. Similarly, previous reviews categorized the model metrics into five categories namely; Process, Technology, Organization, Standard, and Human (Wu et al., 2017, Giel & Issa, 2013).

Some example measures for Process category are “clash analysis process”, “cross disciplinary model coordination”, and “management support” of Multifunctional Maturity Model. Process category’s measures are not comprehensive since there are many AEC/FM processes in different facility life cycle stages. According to RIBA Plan of Work (2013), facility life cycle stages are composed of seven stages which are preparation and brief, concept design, developed design, technical design, construction, handover and close out, and in use. These stages include many processes. For example, architectural design and structural detail design of design stage, select and acquire resources, and build facility of construction stage are few examples of AEC/FM processes. On the other hand, Process measures of some of the models are defined too broadly. For example, “activities/workflows” and “leadership/management” are too broad to be used as measures. Technology category is composed of measures related to technical infrastructure of AEC/FM organizations such as “Software adequacy” and “Hardware adequacy” of VDC Scorecard. Organization category includes measures related to BIM skills of professionals such “VDC training frequency” of VDC Scorecard and BIM visions such as “BIM vision and objectives” of Organizational BIM Assessment Profile. Some of the example measures of Standard category are “VDC guidelines” of VDC Scorecard and “Contracts and agreements” of BIM MM. Human category contains metrics such as “Roles and responsibilities” and “Change readiness” of Organizational BIM assessment Profile.

Moreover, even though some of the models have included a number of BIM uses in their measures, most of the BIM uses which are performed by AEC/FM organizations are not covered. For example, BIM uses namely, “Quantity take-offs”, “Coordination modelling”, “As-Built modelling”, and “Asset management” are defined as measures of the model BIM Proficiency Matrix. In Multifunctional Maturity Model, BIM uses “clash analysis process”, and “cross disciplinary model coordination” are defined as measures of Process category. However, defined BIM uses are not comprehensive in most of the models.

Evaluation approaches: While rating scale of VDC score card is ratio, the rest of the models have ordinal rating scale. They usually have 5 or 10 levels of rating scale. Overall score of most of the models is calculated by weighted sum of measures. VDC Scorecard produces BIM performance score of a project relative to a benchmark dataset which is composed of BIM performance scores of many different AEC/FM organizations in different countries.

BIM maturity is divided into 4, 5 or 6 levels in different models. While NBIMS CMM, BIM QuickScan, Organizational BIM Assessment Profile defined 6 levels of BIM maturity; BIM Proficiency Matrix and BIM MM defined 5, and VDC Scorecard, VICO BIM Scorecard and Multifunctional BIM MM has 4 levels of BIM Maturity.

User support: Only four models, which are BIM Proficiency Matrix, BIM QuickScan, VDC Scorecard and Multi-Functional BIM Maturity Matrix, provides benchmarking functions. Guidelines are created for only Organizational BIM Assessment Profile.

Validation methods: VDC Scorecard have been applied to 150 pilot projects so that it is applicability is tested with different AEC/FM companies. Most of the models are validated though qualitative methods. For example, NBIMS BIM CMM and BIM QuickScan is validated through expert reviews (Wu et al., 2017).

Based on these findings and the recent review paper of Wu et al. (Wu et al., 2017), efficiencies and short comings of each of the model are summarized below.

NBIMS BIM CMM focuses on evaluating BIM maturity of construction projects. It is practical to use for performing an assessment due to its simple structure. It has medium flexibility since weights of its measures are different. It includes 11 measures and six maturity levels. It has qualitative rating approach with ordinal rating scale. It has low coverage of BIM aspects since its eleven measures are classified under single layer. It is validated through pilot projects, user expert interviews and expert reviews. It does not support benchmarking. There are no user guidelines.

BIM Proficiency Matrix is beneficial for selecting sub-contractors. It has low flexibility due to its specific assessment purpose. It has 32 measures in total and five levels of maturity. It has qualitative rating approach with ordinal rating scale. Although its measures are classified under two classification layers; it has low coverage of BIM uses. Because its measures do not include complete BIM uses in the AEC/FM industry. Its validation method is not clear. Although it has benchmarking support, it does not have user guidelines.

BIM Maturity Matrix focuses on evaluating BIM performance of organizations, projects, teams and individuals. It has high flexibility since number measures are adjustable based on the granularity level. It has qualitative evaluation approach with ordinal rating scale and five maturity levels are defined. It has medium coverage of BIM aspects due to its two classification layers. Although, its validation method is not clearly defined, there is an online commercial tool namely, BIM Excellence created based on BIM MM. Users performed online assessments to identify BIM competency of the organizations/teams/individuals' BIM competency. It does not support benchmarking and does not have user guidelines.

Table 5 Comparison of BIM capability and maturity models

Models/Criteria	Measurement Scope and Purpose	Selection and Classification of Metrics	Overall Score and Rating Scale	Definition of Maturity Levels	Validation Method	User Support
NBIMS BIM CMM	Rates performance of projects	11 areas of interests measured against 10 levels of maturity 1 layer	Weighted sum of 11 areas of interests' scores Ordinal rating scale with 5 or 10 levels	Not certified Minimum BIM Certified Silver Gold Platinum	Pilot projects, user interviews, expert reviews	No benchmarkin g and no user guide
BIM Proficiency Matrix	Scores BIM services performances of organizations for selecting subcontractors	32 measures are grouped under8 areas of interests, assed against 4 level of maturity 2 layers	Sum of 8 areas of interests' scores Ordinal rating scale with self-scoring 0 to 1	Working towards BIM Certified BIM Silver Gold Ideal	Not clear	Benchmarkin g support and no user guide
BIM Maturity Matrix	Assesses individual and team BIM competency, organizational capability and maturity and project BIM performance	BIM capability stages, BIM maturity levels, BIM competency sets, organizational scale and granularity level 2 layers	Total points subdivided by the number of competencies, one capability stage and one organizational scale Ordinal rating scale with 5 or 10 levels	Initial Defined Managed Integrated Optimized	Not clear, but organizations/te ams/individuals performed free online assessments via BIM Excellence	No benchmarkin g and no user guide
BIM QuickScan	Provides insight about BIM strengths and weaknesses of the organization	50 questions grouped under 4 categories 2 layers	Weighted sum of all categories points Ordinal rating scale with multiple choice	Ranges from 0 to 5	Pilot projects, expert review, statistical tests	Benchmarkin g support and no user guide

VDC Scorecard	Measures the project performance against an industry benchmark	4 key areas and 10 divisions and 74 individual measures 3 layers	Weighted sum of 4 key areas' scores Ratio rating scale with 5 or 10 levels of scale, multiple choice, quantitative blank filling, open ended questions	Conventional Practice Typical Practice Advanced Practice Best Practice Innovative Practice	Pilot projects, user interviews, expert reviews, statistical tests	Benchmarking support and no user guide
Organizational BIM Assessment Profile	Evaluates the organization's maturity of BIM planning elements	6 main planning elements and 20 sub elements assessed against 6 maturity levels 2 layers	Sum of 20 sub elements' scores Ordinal rating scale with 5 or 10 levels	Non-Existent Initial Managed Defined Quantitatively managed Optimizing	Not clear	No benchmarking and user guide support
VICO BIM Scorecard	Scores the BIM performance of specific BIM uses such as coordination and cost estimation in organizations	7 categories are assessed against 3 three columns and 4 capability levels 2 layers	Weighted sum of 27 questionnaire questions' answers' scores Ordinal rating scale with multiple choice	No capability Low capability Satisfactory capability High capability	Not clear	No benchmarking and no user guide support
Multifunctional BIM Maturity Matrix	Evaluates BIM maturity in projects, companies with a portfolio of projects, and the industry as a whole	3 domains and 21 subdomains are assessed against 4 levels of maturity 2 layers	Equally weighted sum of 21 subdomains' points Ordinal rating scale with 5 or 10 levels	Stage 0 Stage 1 Stage 2 Stage 3	Not clear	Benchmarking support and no user guide

BIM QuickScan provides insight about strengths and weaknesses of BIM usage in an organization. It has medium flexibility since there are variety in its questions. It has 50 questions in total and 6 maturity levels. But, maturity levels are not defined explicitly. It has quantitative evaluation approach with multiple choice questions. It high coverage of BIM aspects due to variety in questions. validated trough pilot projects, expert reviews and statistical tests. Although it supports benchmarking, it does not have user guidelines.

VDC Scorecard scores the project performance against an industry benchmark. It has high flexibility since it is tested in 150 different pilot projects. It has 74 measures in total and five maturity levels. It has both quantitative and qualitative evaluation method with multiple choice quantitative blank and open ended questions. It has high coverage of BIM aspects due to three classification layers of measures. It is validated trough pilot projects, user interviews, expert reviews and statistical tests. Since its rating scale is ratio, it highly supports benchmarking. It does not have user guidelines.

Organizational BIM Assessment Profile focuses on evaluating BIM planning elements. However, it has low flexibility since it focuses on facility owners' needs. It has 20 measures in total and six maturity levels. It has qualitative evaluation approach with ordinal rating scale. It has low coverage of BIM aspects since most of the BIM uses in AEC/FM industry are not included. Its validation method is not clearly defined. It has user guidelines and it does no support benchmarking.

VICO BIM Scorecard focuses on evaluating performance of specific BIM uses in an organization. It has low flexibility since it focuses on evaluating specific BIM uses in an organization. It has 27 questions in total and five capability levels. It has quantitative evaluation approach with multiple choice questions. It has high coverage of BIM aspects since it specifically assesses performance of BIM uses. Its validation method is not defined clearly. It supports benchmarking and it does not have user guidelines.

Multifunctional BIM Maturity Matrix evaluates BIM maturity in projects, in organizations and in industry as a whole. It has medium flexibility since it enables assessment for a single project or organizations with a portfolio of projects or the industry as a whole. It has 21 measures and four maturity levels. It has qualitative evaluation approach with ordinal rating scale. However, it has low coverage of BIM uses since most of the BIM uses in AEC/FM industry are not included. Its validation method is not defined clearly. It supports benchmarking, but it does not have user guidelines.

In addition to the BIM performance assessment models in AEC/FM industry, there are well-known capability and maturity models in software engineering. Besides the models in AEC/FM industry, we also analyzed two of these models in software engineering for understanding their structure. In Section 2.3 we explained each model.

2.3 Capability and Maturity Models in Software Engineering

In software engineering there are a several well-known capability and maturity models. Capability and Maturity Model Integration (CMMI) and ISO/IEC 33000 family of standards are selected to include in the context of this study since they are commonly accepted and broadly used. In this section they are explained briefly and their common parts are identified and presented.

CMMI, is first created by the CMU Software Engineering Institute and later is owned and managed by CMMI Institute. CMMI has three different CMMI models subject to different areas and one CMM for assessing individuals. These are:

- CMMI for Development (CMMI-DEV) provides guidance for improving capability of development processes (SEI, 2010b).

- CMMI for Services (CMMI-SVC) is a guideline for improving capability of providing quality services to customers (SEI, 2009a).

- CMMI for Acquisition (CMMI-ACQ) aims to improve capability of managing product and services acquisitions (SEI, 2010a).

- People Capability and Maturity Model (PCMM) provides guidance for improving capability of an organization's work force (SEI, 2009b).

CMMI-DEV defines key process areas such as requirements development, validation, verification. It includes 22 key process areas such as Configuration Management, Product Integration and Project Planning. Of those process areas, 16 are the core processes, 5 of them are development specific and 1 is a shared process area (SEI, 2010b). CMMI-ACQ includes 22 process areas such as Agreement Management, Acquisition Validation and Acquisition Verification. Of those 16 are the core process areas, 5 of them are acquisition specific and 1 is a shared process area (SEI, 2010a). CMMI-SVC includes 24 process areas such as Capacity and Availability Management, Organizational Training and Work Monitoring and Control. Of those processes 16 are the core process areas, 7 of them are service specific process areas and one is a share process area (SEI, 2009a). All CMMI models contain 16 core process areas and for each process area the model contains components such as purpose statement, generic goals, specific goals, generic practices and specific practices. CMMI supports two improvement approaches namely continuous representation and staged representation. Continuous representation focuses on specific processes and used to state the capability level of the specific processes. Four capability levels, which are L0 – Incomplete, L1 – Performed, L2 – Managed, and L3 – Defined, are used for process improvement in individual process areas. Staged representation is used to state the maturity of the organization. Five maturity levels, which are L1 – Initial, L2 – Managed, L3 – Defined, L4 – Predictable, and L5 – Optimizing, are used to achieve process improvement across multiple process areas (SEI, 2010b). PCMM includes 22 process areas such as Workgroup Management, Training and Development and Staffing. PCMM is presented only in a staged representation which has five maturity levels namely, L1 – Initial, L2 – Managed, L3 – Defined, L4 – Predictable, and L5 – Optimizing (SEI, 2009b).

Along with these models, Standard CMMI Appraisal Method for Process Improvement (SCAMPI) is used to for conducting appraisals for CMMI models. It is composed of three phases which are 1 – Plan and prepare for appraisal, 2 – Conduct appraisal and 3 – Report result. It provides integrated appraisal method for internal process improvement, supplier selection, and process monitoring (SCAMPI Upgrade Team, 2011).

Another important process assessment standard is ISO/IEC 33000 family of standards. The recent ISO/IEC 33000 replaces the ISO/IEC 15504 – Software Process Improvement and Capability

Determination (SPICE) which provides guidance on how to utilize process assessment for conducting process improvement.

ISO/IEC 15504 have five parts. Part 1 describes the concepts and vocabulary used within the SPICE (ISO/IEC, 2000). The rest of the four parts are as follows:

- ISO/IEC 15504:2 – Performing an assessment describes the capability levels and process attributes within the process measurement framework. Additionally, requirements for process assessment models are summarized (ISO/IEC, 2012a).

- ISO/IEC 15504:3 – Guidance on performing an assessment defines the assessment activities which are 1 – Initiation, 2 – Planning, 3 – Briefing, 4 – Data collection, 5 – Data validation, 6 – Process attributes rating, and 7 – Assessment reporting (ISO/IEC, 2012b).

- ISO/IEC 15504:4 – Guidance on use for process improvement and process capability determination provides guidance for process improvement and capability determination by defining the strengths, weaknesses, and process-related risks. Process improvement cycle is composed of eight steps which are 1– Examine organization's business goals, 2 – Initiate process improvement cycle, 3 – Assess current capability, 4 – Develop action plan, 5 – Implement improvements, 6 – Confirm improvements, 7 – Sustain improvements, and 8 – Monitor performance (ISO/IEC, 2004).

- ISO/IEC 15504:5 – An exemplar process assessment model provides an example of a process assessment for performing a conformant assessment in terms of the instructions written in ISO/IEC 15504-2 (ISO/IEC, 2006).

Since structured process assessment approach of ISO/IEC 15504 were adapted into various different domains, two important parts are included in the recently published ISO/IEC 33000. These two parts are ISO/IEC 33003 and ISO/IEC 33004 and each of them explains requirements and rules for developing process reference models and measurement frameworks, respectively. ISO/IEC 33000 family of standards is composed of ten parts. ISO/IEC 33001, first part introduces and defines concepts and terms which are used in all parts (ISO/IEC, 2015). The rest of the parts are given and described as follows:

- ISO/IEC 33002, defines requirements for performing a process assessment (ISO/IEC, 2015b).

- ISO/IEC 33003, provides requirements for developing process measurement frameworks (ISO/IEC, 2015c).

- ISO/IEC 33004, provides requirements for development of process reference, process assessment and maturity models (ISO/IEC, 2015d).

- ISO/IEC 333014, is a guideline for using process assessment results and creating process improvement road maps (ISO/IEC, 2013).

- ISO/IEC 33020, defines a process measurement framework which is used for assessing capabilities of a selected process (ISO/IEC, 2015).

- ISO/IEC 33052, is a process reference model for information security management and describes the processes related to information security management system (ISO/IEC, 2016a).

- ISO/IEC 33063, is a process assessment model for software testing and contains a set of process quality characteristics to be used for assessing capabilities of software testing processes (ISO/IEC, 2015f).

- ISO/IEC 33071, introduces an integrated process assessment model for enterprise processes which integrates selected process models and standards into a single model (ISO/IEC, 2016b).

- ISO/IEC 33072, introduces an information security management process assessment model which is composed of both a process reference model and a process measurement framework (ISO/IEC, 2016c).

According to ISO/IEC 33002, process assessment is composed of five steps including planning, data collection, data validation, process attribute rating, and reporting (ISO/IEC, 2015b). Details of ISO/IEC 33003 and ISO/IEC 33004 are explained in Sections 2.4.2 and 2.4.1, respectively.

In ISO/IEC 333014, process improvement has eight steps which are 1 – Examining organization's business goals, 2 – Initiating process improvement cycle, 3 – Assessing current capability, 4 – Developing action plan, 5 – Implementing improvements, 6 – Confirming improvements, 7 – Sustaining improvements, and 8 – Monitoring performance (ISO/IEC, 2013).

In ISO/IEC 33020, process measurement framework is composed of three major elements which are capability levels, process attributes, and rating scale. Six capability levels and nine process attributes are defined in total. Those process attributes are rated by using the performance indicators defined in the model. In order to depict the results, ordinal scale is used (ISO/IEC, 2015). Detailed information regarding to Part 6 is presented in Section 2.4.2.

ISO/IEC 33052 is process reference model for information security management domain and is created in conformance to Part 4. ISO/IEC 33063, ISO/IEC 33071 and ISO/IEC 33072 are created by adapting the original process assessment model into different domains which are, software testing, enterprise processes, and information security management, respectively.

When structure of CMMI, and ISO/IEC 33000 are analyzed in detail, it is identified that they establish process assessment architecture of four components:

a) Process reference model, which defines processes which are subject of assessments,

b) Process measurement framework, which provides measures for evaluating process quality characteristics such as capability levels and maturity levels,

c) Documented procedures and requirements, for conducting process assessments, and

d) Process improvement method, for utilizing process assessment results ad deriving process improvement road maps.

Table 6 presents that which part/parts ([a], [b], [c], [d]) are contained by which standards. For example, ISO/IEC 12207 – Systems and Software Engineering, Software Life Cycle Processes (ISO/IEC, 2008) includes definitions of systems and software lifecycle processes and is used for performing software processes assessment though ISO/IEC 15504-2 and ISO/IEC 33020. ISO/IEC 33052 is process reference model which includes process definitions for Information Security Management. ISO/IEC 33063, ISO/IEC 33071 and ISO/IEC 33072 are process assessment models and each of which includes both process definitions and measurement framework within the specific domains namely Software Testing, Enterprise Processes and Information Security Management, respectively.

Table 6 Parts contained by ISO/IEC 15504, ISO/IEC 33000 and CMMI

Name	Content	Parts Contained
ISO/IEC 12207	Includes definitions of systems and software life cycle processes	[a]
ISO/IEC 33052	Includes definitions of Information Security Management processes	[a]
ISO/IEC 15504-3 ISO/IEC 33002	Establishes a structured approach for performing process assessments	[c]
ISO/IEC 15504-2 ISO/IEC 33020	Process assessment measurement framework including capability levels and process attributes 6 maturity levels	[b]
ISO/IEC 15504-4 ISO/IEC 33014	Provides guidance on process improvement	[d]
ISO/IEC 33000 (parts 63, 71, 72)	Process assessment models for Software Testing, Enterprise Processes and Information Security Management Defines 6 Capability levels for Parts 63 and 72 Defines 2 Capability Levels for Part 71	[a] [b]
CMMI (DEV, SVC, ACQ)	Defines best practices to provide a guideline for process improvement Defines 4 Capability Levels in Staged and 5 Maturity Levels in Continuous Representation	[a] [b]
SCAMPI	Defines how to conduct appraisal based on CMMI to create process improvement action plan	[c] [d]

As presented in Table 6, ISO/IEC 15504-3 and ISO/IEC 33002 establish structured approach for performing process assessments. ISO/IEC 15504-4 and ISO/IEC 33014 provide guidance on how to conduct process improvement by using process assessment results. CMMI-DEV, CMMI-SVC and CMMI-ACQ also include process definitions and measures for performing appraisals in Development, Services and Acquisition, respectively. SCAMPI provides a basis for conducting appraisals by using CMMI models, which are CMMI-DEV, CMMI-SVC, CMMI-ACQ and PCMM.

2.4 Structure of ISO/IEC 33000 Family of Standards

ISO/IEC 33000 has a well-defined structure which is composed of the parts described in Section 2.3. Process assessments which are performed based on the structured approach of ISO/IEC 33000 family of standards enables organizations to understand current state of their own software processes for a requirement, and to determine the current state of supplier's software processes for a contract (Pyhäjärvi, 2004). Process assessment by using ISO/IEC 33000 family of standards facilitates self-assessment, provides a basis for process improvement and risk mitigation, provides a benchmark within a software organization and across organizations, and is applicable across all sizes of organizations. Furthermore, the structure of ISO/IEC 15504 also allows separate evaluation and improvement of processes which increases the flexibility of the model. Therefore, we selected to use the meta-model of ISO/IEC 33000 for theoretical development of BIM-CAREM.

Process assessment through ISO/IEC 33000, is performed mainly based on two dimensions which are process dimension and quality dimension (ISO/IEC, 2015). Process dimension is a set of process elements and related to Process Reference Model (PRM) (ISO/IEC, 2015a). Process quality dimension is set of quality elements of the Process Measurement Framework (MF) for the defined process quality characteristics (ISO/IEC, 2015a). We decided to develop two dimensions for BIM-CAREM which are process dimension and BIM capability dimension which are related to Building Process Reference Model (Building PRM) and BIM Process Reference Model (BIM PRM), and BIM Measurement Framework (BIM MF), respectively. Therefore, in Sections 2.4.1 and 2.4.2, we explained requirements for development of PRM and Process MF, respectively.

2.4.1 *ISO/IEC 33004 Requirements for Process Reference Models*

The purpose of a PRM is to define a set of processes which supports objectives of a domain area. It provides basis for performing process assessments. Process reference model helps to define scope of the assessment and definitions of inter-related processes. It has two components, which are domain and scope, and process purpose and process outcomes. It is required to have the following points (ISO/IEC, 2015d):

- declaration of the domain of the process reference model, and
- set of processes and descriptions of the processes.

Process descriptions are the fundamental element of a process reference model. Processes are required to defined in terms the following two components (ISO/IEC, 2015d):

- Process purpose, and
- Process outcomes.

The purpose of the process is stated as a high level, overall goal for performing the process (IEEE, 2012). A process outcome is an observable result of the successful achievement of the process purpose. Outcomes are observable and assessable results such as technical or business results which are achieved by a process (IEEE, 2012). A process outcome describes one of the following (ISO/IEC, 2015d):

- production of an artifact,
- a significant change of state, and
- meeting of specified constraints such as requirements and goals.

According to stated requirements in ISO/IEC 33004 (ISO/IEC, 2015) and ISO/IEC 24774 (IEEE, 2012), we declared that the domain of the Building PRM and BIM PRM is AEC/FM domain. In addition to this, a process definition template, which is shown in Figure 3, is created and used for defining each AEC/FM process in Building Process Reference Model (Building PRM) and BIM Process Reference Model (BIM PRM).

Process ID	
Process name	
Process purpose	
Process outcomes/BIM outcomes	
Base practices	

Work Products

Base Practice	**Inputs**	**Outputs**

Figure 3 Process definition template used in BIM-CAREM

This template is used for defining selected key AEC/FM processes and definition procedure of the processes is explained in detail in Section 3.1.1.

2.4.2 *ISO/IEC 33003 Requirements for Process Measurement Frameworks and ISO/IEC 33020 Process Measurement Framework for Process Capability Assessment*

Process MF enable assessment of process quality characteristics for producing composite measures. According to the ISO/IEC 33003 (ISO/IEC, 2015c); in which requirements for developing a Process MF are explained, a Process MF is composed the following components:

1. Identifying and defining capability levels,
2. Defining a set of process attributes for each process capability levels and these attributes are required to be observable and to represent the properties of process capability levels, and
3. A rating scale is required to rate process attributes in formal assessments.

After defining these components, measurement frameworks are required to be validated. Definition of each requirement is explained under the following titles.

Process Capability Levels*:* A measurement framework is required to identify single process quality characteristics such as process capability level. Most of the quality characteristics are not observable but theoretical constructs. Construct is a concept such as idea, underlying theme, which is measured by process assessments (ISO/IEC, 2015c).

Process Attributes*:* A quality characteristic is required to be defined a set of process attributes which define properties of the quality characteristic. Process attributes can be either reflective or formative. Achievement of process attributes is required to be verified through object evidence. Process attribute outcomes may be characterized as an intermediate step to providing a process attribute rating (ISO/IEC, 2015c).

Rating Scale and Aggregation: A process measurement framework is required to include a rating scale which can be either nominal, ordinal, interval, or ratio. Each process attribute is required to be assigned a value based on the defined measurement method. An aggregation method is required to be defined for deriving composite rating by combining single ratings of process attributes. It is required to be consistent with the rating scale (ISO/IEC, 2015c).

Validation of Measurement Frameworks*:* Reliability and validity of process measurement framework and construct specifications are required to be examined at the beginning of the standardization (ISO/IEC, 2015c).

Table 7 presents the terminology, which is used in measurement framework of BIM-CAREM. They are created in conformance to ISO/IEC 33003 (ISO/IEC, 2015)

Table 7 Terminology used in BIM MF

Terminology in ISO/IEC 33003	**Terminology in BIM-CAREM**
Process Capability Assessment Model	BIM Capability Assessment Model
Process Measurement Framework	BIM Measurement Framework
Process Capability Levels	BIM Capability Levels
Process Attribute	BIM Attribute
Process Attribute Outcome	BIM Attribute Outcome
Rating Scale	Rating Scale

ISO/IEC 33020 – Process Measurement Framework for Assessment of Process Capability is developed based on the defined requirements. It provides a schema which enables process assessment for assessing process capability in software engineering (ISO/IEC, 2015). Each process capability is represented by a set of process attributes which are measureable properties of process capabilities. Process MF in ISO/IEC 33020 is composed of six point of ordinal scale which is as follows (ISO/IEC, 2015):

- Level 0 – Incomplete Process
- Level 1 – Performed Process
    - PA 1.1 Process Performance Process Attribute
- Level 2 – Managed Process
    - PA 2.1 Performance Management Process Attribute
    - PA 2.2 Work Product Management Process Attribute
- Level 3 – Established Process
    - PA 3. 1 Process Definition Process Attribute
    - PA 3.2 Process Deployment Process Attribute
- Level 4 – Predictable Process
    - PA 4.1 Quantitative Analysis Process Attribute
    - PA 4.2 Quantitative Control Process Attribute
- Level 5 – Innovating Process
    - PA 5.1 Process Innovation Process Attribute
    - PA 5.2 Process Innovation Implementation Process Attribute

In ISO/IEC 33020, process attributes are rated based on the below rating scale (ISO/IEC, 2015):

- N Not Achieved 0 to ≤15% achievement,
- P Partially Achieved > 15% to ≤50% achievement,
- L Largely Achieved > 50% to ≤85% achievement, and
- F Fully Achieved > 85% to ≤100% achievement.

In order to have composite rating by aggregating single ratings of process attributes, two aggregation methods are recommended in ISO/IEC 33020. The first one is aggregation using arithmetic mean and the second one is aggregation using median (ISO/IEC, 2015).

These ordinal values, namely N, P, L, and F, are converted into interval values 3, 2, 1, and 0, respectively. After having these interval values, the following aggregation methods can be applied.

Aggregation Using Arithmetic Mean: Average of the ratings are calculated. When rounding is required, the result is rounded down to the nearest integer when the average is less than the midpoint, or rounded up if the average is at or above the midpoint. The final result is converted back to the corresponding ordinal value (ISO/IEC, 2015).

Aggregation Using Median: Median of the single ratings are calculated. If there is odd number of values, the result is the middle value. On the other hand, if there is even number of values, average of the two middle values is calculated. The result is rounded down or up based on the above rules if the average is a real number. The final result is converted back to the corresponding ordinal value (ISO/IEC, 2015).

For the achievement of a process capability level, associated process attributes must be rated as largely achieved of fully achieved (ISO/IEC, 2015).

CHAPTER 3

BIM-CAREM: A REFERENCE MODEL FOR BIM CAPABILITY ASSESSMENT

This chapter presents the evolving process of BIM-CAREM to answer research questions RQ1 and RQ2 and their sub questions RQ1.1, RQ1.2 and RQ2.1. Preliminary BIM-CAREM is grounded on the meta-model of ISO/IEC 33000 standards which is explained in Chapter 2.

As described in Section 2.4, BIM-CAREM is composed of two dimensions which are process dimension and BIM capability dimension. Process dimension is represented by two process reference models which are Building PRM and BIM PRM. BIM capability dimension is represented by a measurement framework which is BIM MF. Figure 4 shows the performed research tasks for developing BIM-CAREM conceptually. Performed research tasks for theoretical development of process reference models and measurement framework are represented with branches Blue and Green, respectively in Figure 4.

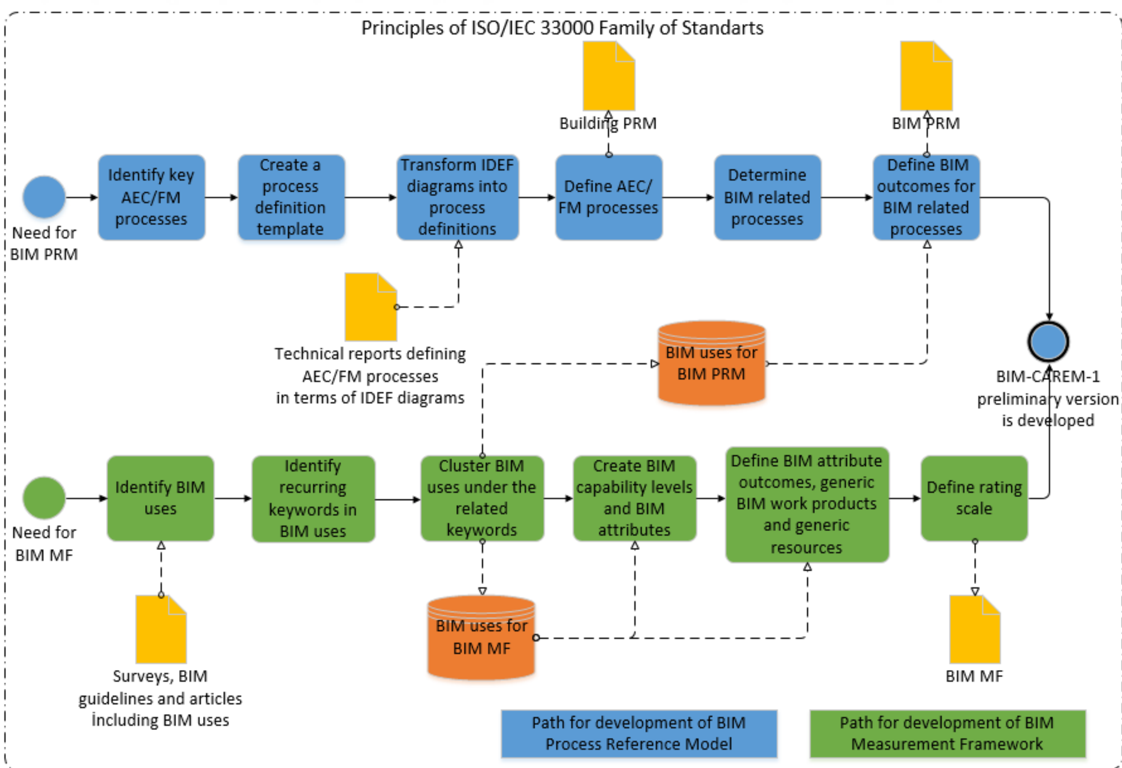

Figure 4 Performed research tasks for theoretical development of BIM-CAREM

Building PRM and BIM PRM are developed by answering research questions RQ1, RQ1.1 and RQ1.2, and development of these process reference models is composed of three main research tasks which are given in Figure 4 as follows:

1. Identifying key AEC/FM processes in order to cover all facility life cycle stages,

2. Defining each AEC/FM process in conformance to ISO/IEC 33004 (ISO/IEC, 2015), and

3. Determining BIM related processes and defining BIM outcomes for each of them.

Similarly, BIM MF is developed by answering research questions RQ2 and RQ2.1 and development of this measurement framework is composed of two main research tasks which are given in Figure 4 as follows:

1. Creating BIM capability levels and BIM attributes for utilizing in BIM capability assessment of a building process, and

2. Defining a rating scale.

First version of BIM-CAREM, which is the preliminary model, provided a point of departure for further developing the model iteratively. The development of the model followed two iterations and one approval by means of expert reviews and an exploratory case study. We explained the theoretical development of BIM-CAREM and structure of the third version of BIM-CAREM, which is the final version, in Section 3.1. Evolving process of BIM-CAREM through iterations and the approval by means of expert reviews and an exploratory case study is explained in Section 3.2 and in Section 4.3, respectively.

3.1 Structure of BIM-CAREM

BIM-CAREM is a reference model for assessing BIM capability of AEC/FM organizations' processes. BIM capability assessment by means of BIM-CAREM enables organizations to understand existing BIM capability of AEC/FM processes. The assessment results provide a baseline for improvements in BIM usages and risk mitigation. It allows users to make multiple evaluations for the same process, and enables formal appraisals and benchmarking. The structure of BIM-CAREM allows separate evaluation and improvement of processes which increases the flexibility. For example, assessors can choose one or more processes from BIM PRM such as "Make Architectural Detail Design" and "Monitor Facility Conditions and Systems", and evaluate BIM capabilities of these processes separately by using BIM MF. This enables us to compare specific processes within and across the organizations. Moreover, it can be used to determine current state of sub-contractors' AEC/FM processes for selection.

As presented in Figure 5, BIM-CAREM has two dimensions which are BIM process dimension, and BIM capability dimension. BIM process dimension is composed of a set of process elements related to BIM, and represented by two process reference models namely Building PRM and BIM PRM. BIM capability dimension is composed of a set of BIM capability levels and their associated attributes, and represented by a measurement framework which is BIM MF.

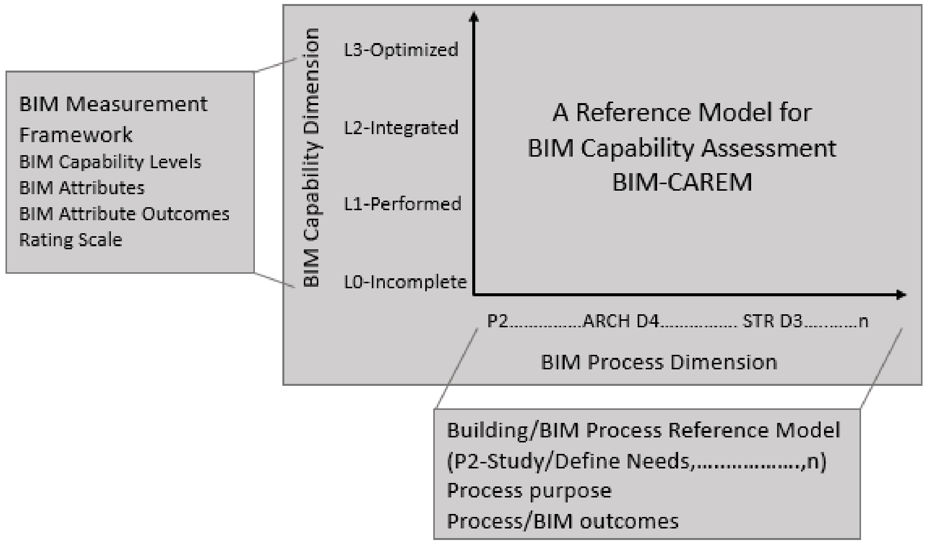

Figure 5 Parts of BIM-CAREM (Adapted from Figure 1 in ISO/IEC, 2015)

The domain of the process reference models namely, Building PRM and BIM PRM is AEC/FM industry. While Building PRM comprises definitions of in terms of process purpose and process outcomes, BIM PRM comprises definitions of BIM related AEC/FM processes in terms of process purpose and BIM outcomes. BIM MF is the schema which is used for characterizing BIM capability of an implemented AEC/FM process. Development and structure of the process reference models and the measurement framework are explained in detail in Sections 3.1.1 and 3.1.2, respectively.

3.1.1 *Building Process Reference Model and BIM Process Reference Model*

Before BIM PRM, we first created Building PRM. Development of Building PRM started with identifying key AEC/FM processes to cover all facility life cycle phases. In order to achieve this, we studied RIBA Plan of Work which is composed of eight facility life cycle stages. These stages are Strategic Definition, Preparation and Brief, Concept Design, Developed Design, Technical Design, Construction, Handover and Close Out, and In Use (RIBA, 2013). By taking the RIBA stages as baseline, we covered the following four main facility life cycle stages:

1. Conceptual Planning,
2. Design,
3. Construction, and
4. Facility Management.

After we identified the facility life cycle stages, we followed the six research tasks, which are presented in Figure 4, for developing Building PRM and BIM PRM. These six research tasks are as follows:

1. Identifying AEC/FM processes to cover all facility life cycle stages,

2. Creating a process definition template in conformance to ISO/IEC 33004 (ISO/IEC, 2015) and ISO/IEC 24774 (IEEE, 2012),

3. Transforming IDEF diagrams, which are given in two technical reports, into process definitions in terms of process purpose and process outcomes by using process definition template,

4. Defining building processes in terms of process purpose and process outcomes,

5. Determining BIM related processes, and

6. Defining BIM outcomes for BIM related processes.

Process is a set of interrelated or interacting activities of facility life cycle stages and transforms inputs into outputs (ISO/IEC, 2015). In order to identify key AEC/FM processes of each facility life cycle stage, two technical reports, namely, “An Integrated Building Process Model” (CIC, 1990) and “Construction Process Model” (VTT, 1997), are studied. Both of these technical reports covers all facility life cycle stages and have a list of key AEC/FM processes of each phase. However, the VTT’s technical report focuses on processes of separated design disciplines as architectural, structural, building services and geotechnical design. Due to detailed descriptions of each design discipline, design phase is defined based on this technical report. Conceptual planning, construction and facility management phases are described based on the CIC’s technical report. Key AEC/FM processes with respect to each phase and their relations to BIM are presented in Table 8. BIM relation of each process is identified based on the results of natural language analysis which is explained in detail in Section 3.1.2.

Table 8 BIM-CAREM's facility life cycle phases and processes and their relations to BIM

Phase/Process ID	**Phase/Process Name**	**Related to BIM? (Y/N)**
P (Phase)	**Conceptual Planning**	
P1	Assign Planning Team	N
P2	Study/Define Needs	Y
P3	Study Feasibility	Y
P4	Develop Program	N
P5	Develop Project Execution Plan	Y
P6	Select and Acquire Site	Y
ARCH D (Phase)	**Architectural Design**	
ARCH D1	Draw Up Brief	N
ARCH D2	Draw Up Program	Y
ARCH D3	Make Global Design	Y
ARCH D4	Make Detail Design	Y
ARCH D5	Do Design Tasks During Construction	Y
STR D (Phase)	**Structural Design**	
STR D1	Draw Up Brief	N
STR D2	Draw Up Program	N
STR D3	Make Global Design	Y
STR D4	Make Detail Design	Y
STR D5	Do Design Tasks During Construction	Y
BS D (Phase)	**Building Services Design**	

BS D1	Draw Up Brief	N
BS D2	Draw Up Program	N
BS D3	Make Global Design	Y
BS D4	Make Detail Design	Y
BS D5	Do Design Tasks During Construction	Y
GEO D (Phase)	**Geotechnical Design**	
GEO D1	Draw Up Brief	N
GEO D2	Draw Up Program	N
GEO D3	Make Global Design	Y
GEO D4	Make Detail Design	Y
GEO D5	Make Tasks During Construction	Y
C (Phase)	**Construction**	
C1	Acquire Construction Services	Y
C2	Plan and Control the Work	Y
C3	Provide Resources	Y
C4	Build Facility	Y
FM (Phase)	**Facility Management**	
FM1	Plan/Control Facility	Y
FM2	Manage Operations	Y
FM3	Monitor Facility Conditions And Systems	Y
FM4	Evaluate Conditions and Detect Problems	Y
FM5	Develop Solutions	Y
FM6	Select Plan of Action	Y
FM7	Implement Plan	Y

After determining key AEC/FM processes, it is required to have a process definition template, to define each process systematically and in same format for all process definitions. Therefore, a process definition template is created in conformance to ISO/IEC 33004 (ISO/IEC, 2015d) and ISO/IEC 24774 (IEEE, 2012) which is presented in Table 9. This template is also presented in Section 2.4.1, before. Each process is defined by using this format both in Building PRM and BIM PRM. Furthermore, the requirements explained in ISO/IEC 33004 (ISO/IEC, 2015d) which are described in section 2.4 are taken as basis for creating process definitions.

Table 9 Building/BIM PRM processes definition template

Process ID	indicates the ID of a process
Process name	is the title of a process
Process purpose	indicates the high level objective of performing the process (ISO/IEC, 2015a)
Process outcomes (applicable to Building PRM)	is an observable and assessable result of the successful achievement of the process purpose (ISO/IEC, 2015a)
BIM outcomes (applicable to BIM PRM)	is an is an observable and assessable result of the successful achievement of the process purpose in terms of BIM
Base practices	is an activity of a set of activities which contributes to process purpose achievement (ISO/IEC, 2015a)

Both of the technical reports have definitions of AEC/FM processes in terms of building process models namely, IDEF diagrams which contain a set of functions. Structure of an IDEF diagram is presented in Figure 6 and the "Make Architectural Detail Design" process of the Architectural Design phase is given as an example. An IDEF diagram is composed of five components as depicted in Figure 6. Main component of the diagram is the function which is an activity and described by an active verb and shown by a box. Each function has four elements namely input, output, control, and mechanism. Input and output are entities that undergo the function and the result of a function, respectively. They can be information, material, and etc. Control influences the function such as limiting the activity. Mechanism represents roles of functions such as person or machine (CIC, 1990).

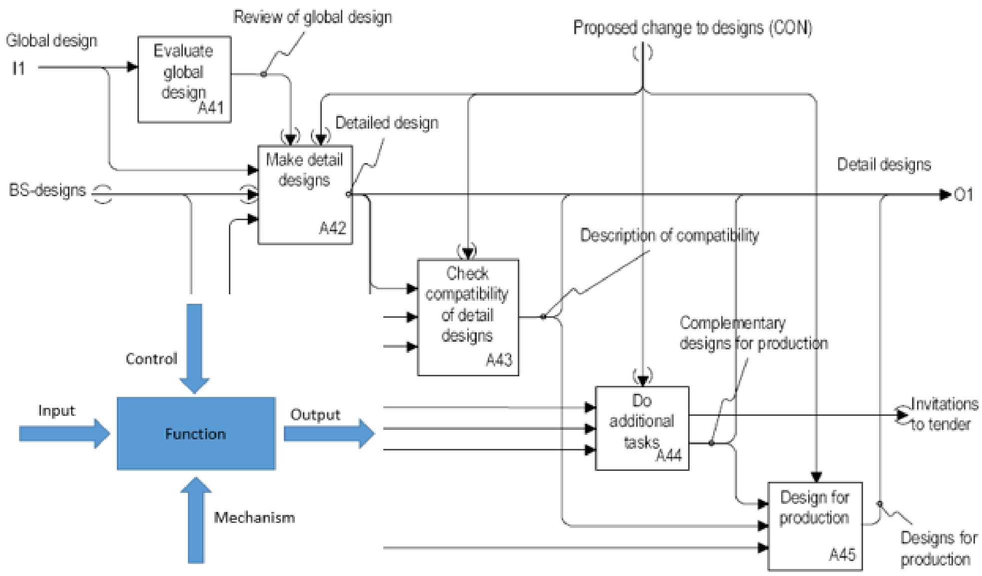

Figure 6 IDEF structure and Make Architectural Detail Design IDEF diagram (VTT, 1997)

IDEF diagrams of AEC/FM processes are transformed into process descriptions. The process definition template table, which is the Table 9, is used for defining all AEC/FM processes. This template is composed of six fields which are Process ID, Process Name, Process Purpose, Process Outcomes, Base Practices, and Work Products. Definition of each field is given in Table 9.

Process purpose is created from detailed descriptions of processes in technical reports. Base practices are formed by using functions of IDEF diagrams. For example, the functions of the IDEF diagram "Make Architectural Detail Design" are presented in Figure 6 as Evaluate Global Design, Make Detail Designs, Check Compatibility of Detail Designs, Do Additional Tasks, and Design for Production. These functions are transformed into base practices for the process "Make Architectural Detail Design" which is defined in Table 10. Process outcomes are created based on the outputs of the processes' IDEF diagrams. For example, five outcomes of the "Make Architectural Detail Design" which are Global Design Review, Detailed Architectural Design, Coordination, Tenders and Detailed Designs, are created based on the outputs of the IDEF diagram given in Figure 6.

Table 10 Process description of Make Architectural Detail Design in Building PRM

Process ID	ARCH D4
Process name	Make Detail Design (Detail Design & Construction Documents)
Process purpose	The purpose of the Make Detail Design is to create detail designs for tendering.
Process outcomes	As a result of successful implementation of Make Detail Design: 1. Global design is reviewed. 2. Detailed ARCH design is developed. 3. Coordination is conducted with all design disciplines. 4. Tenders are created. 5. Detail designs for construction is prepared.
Base practices	1. Evaluate global design: Evaluate global design solutions. (Outcome 1) **(BIMout 1)** 2. Make detail designs: Design architectural detailed design such as facades, spaces, basements, and roof structures. (Outcome 2) (**BIMout 2)** 3. Check compatibility of detail designs: Check coordination with all disciplines. (Outcome 3) **(BIMout 3)** 4. Do additional tasks: Create invitations to tender. (Outcome 4) **(BIMout 5,6,9)** 5. Architectural detail design for construction: Create architectural detail design for construction. (Outcome 5) **(BIMout 4,7,8)**

Lastly, work products are created based on inputs and outputs of the IDEF diagrams. Work products of "Make Architectural Detail Design" are presented in Table 11. Work products which are same as the process outcomes are marked in work products table which is visualized in Table 11. For example, the work product "Review of Global Design" given in Table 11 is marked as Outcome 1 which is "Global design is reviewed" as given in Table 10.

Table 11 Work products of Make Architectural Detail Design

Work Products	
1. Global design	7. Review of global design (Outcome 1)
2. ARCH detailed design (Outcome 2)	8. BS designs
3. Construction specification (Outcome 2)	9. STR designs
4. Description of design compatibility (Outcome 3)	10. Complementary designs for construction (Outcome 4)
5. Component suppliers designs	11. Invitations to tender (Outcome 4)
6. ARCH designs for construction (Outcome 5)	

Work products are classified into inputs and outputs for each base practice which is depicted in Table 12. For example, Base Practice 1 of "Make Architectural Detail Design" has one input and one output as presented in Table 12.

Table 12 Inputs and outputs of Make Architectural Detail Design's base practices

Base Practice	Inputs	Outputs
BP1	1	7

BP2	1,8,9	2,3
BP3	2,8,9	4
BP4	2,5	10,11
BP5	2,4	6

Definition of "Make Architectural Design" in Building PRM is presented in Table 10, 11 and 12. Each process in Building PRM is defined by using the same format as the "Make Architectural Detail Design". In total, thirty-seven key AEC/FM processes are defined in Building PRM. Definitions of all processes are included in Building PRM which is given in Appendix A.

Since these two technical reports are not recent publications, they do not contain BIM aspect. It is required to have BIM aspect in AEC/FM process definitions. In order to solve this problem, we interviewed a number of AEC/FM professionals and realized that processes and the base practices of traditional construction industry remain the same. However, way of working has changed into BIM integrated project deliveries. By considering these issues, we decided to mark the BIM related processes first and later to define BIM outcomes instead of process outcomes. Twenty-eight processes are marked as BIM related processes which can be seen in Table 8.

Instead of "Process Outcomes" in Building PRM, "BIM Outcomes" are defined for each BIM related process in BIM PRM. BIM outcomes are generated based on the results of natural language analysis which is conducted on the BIM uses found from literature. Recurring nouns and verbs are identified by using RapidMiner and presented in Table 13. BIM uses are clustered under these keywords and used to generate BIM outcomes in BIM PRM. Details of natural language analysis are explained in section 3.1.2. Clustered BIM uses are given as a complete list in Appendix D.

Table 13 Recurring keywords utilized for development of BIM Outcomes

Keyword	No of Occurrences	Keyword	No of Occurrences
Design	27	Review	5
Construct	22	As built	5
Site	20	Real time	5
Analysis	19	Edit	4
Manage	13	Laser scanning	3
Plan	12	Feasibility/Bid	3
Cost	10	Green	3
Schedule	10	Sustain	2
Fabrication	7	Program	2
Coordination	5	Clash detection	1
Visualization	5	Rule checking	1

"Make Architectural Detail Design" in BIM PRM is presented in Table 14. For example, Design Review, Design Authoring, Coordination, Cost Estimating, Phase and 4D Planning, and Engineering Analysis are created as BIM outcomes for this process by using the clustered BIM uses.

Table 14 Process description of Make Architectural Detail Design in BIM PRM

Process ID	ARCH D4
Process name	Make Detail Design (Detail Design & Construction Documents)
Process purpose	The purpose of the Make Detail Design is to develop the model in detail for production and tenders.
BIM outcomes	As a result of successful implementation of Make Detail Design: 1. Design review: Design review is conducted for ARCH global model. (Essential BIM Use) 2. Design authoring: Detailed architectural model is authored. (Essential BIM Use) 3. Coordination: 3D coordination is conducted between detailed architectural model and all other detailed models (STR, BS, GEO). (Essential BIM Use) 4. Design authoring: Architectural detail model is updated further for construction. (Essential BIM Use) 5. Cost estimating: 5D cost estimating is created via quantity take off from the model. (Enhanced BIM Use) 6. Phase and 4D planning: 4D planning is prepared to plan construction sequence effectively. (Enhanced BIM Use) 7. Engineering analysis: Energy analysis is conducted based on the model to asses building energy performance. (Enhanced BIM Use) 8. Engineering analysis: Sustainability (LEED) evaluation is done based on the model. (Enhanced BIM Use) 9. Tender documents including BIM protocols are created.

We tagged BIM outcomes with one of the two values namely, Essential BIM Use and Enhanced BIM Use which are defined in National BIM Guide for Owners (2017). Essential BIM uses are the fundamental BIM uses which are perquisites to implement Enhanced BIM uses. Some example Essential BIM uses are design authoring and coordination. Enhanced BIM uses are the advanced BIM practices such as cost estimating, and phase and 4D planning. However, we could not have tagged some of the BIM outcomes, since these BIM uses are not included in the National BIM Guide for Owners. Very well-known BIM uses such as design authoring, engineering analysis and asset management are defined in this report. For example, ninth BIM outcome in Table 14 does not have a tag.

In Figure 7, “Make Architectural Detailed Design” is presented as represented in both of the reference models. BIM outcomes are mapped to the base practices of the same processes in Building PRM. Therefore, traceability between the two process reference models which are Building PRM and BIM RPM is maintained via base practices.

Process ID	ARCH D4
Process name	Make Detail Design (Detail Design & Construction Documents)
Process purpose	The purpose of the Make Detail Design is to create detail designs for tendering.
Process outcomes	As a result of successful implementation of Make Detail Design: 1. Global design is reviewed. 2. Detailed ARCH design is developed. 3. Coordination is conducted with all design disciplines. 4. Tenders are created. 5. Detail designs for construction is prepared.
Base practices	1. Evaluate global design: Evaluate global design solutions. (Outcome 1) **(BIMout 1)** 2. Make detail designs: Design architectural detailed design such as facades, spaces, basements, and roof structures. (Outcome 2) **(BIMout 2)** 3. Check compatibility of detail designs: Check coordination with all disciplines. (Outcome 3) **(BIMout 3)** 4. Do additional tasks: Create invitations to tender. (Outcome 4) **(BIMout 5,6,9)** 5. Architectural detail design for construction: Create architectural detail design for construction. (Outcome 5) **(BIMout 4,7,8)**

Process ID	ARCH D4
Process name	Make Detail Design (Detail Design & Construction Documents)
Process purpose	The purpose of the Make Detail Design is to develop the model in detail for production and tenders.
BIM outcomes	As a result of successful implementation of Make Detail Design: 1. Design review: Design review is conducted for ARCH global model. (Essential BIM Use) 2. Design authoring: Detailed architectural model is authored. (Essential BIM Use) 3. Coordination: 3D coordination is conducted between detailed architectural model and all other detailed models (STR, BS, GEO). (Essential BIM Use) 4. Design authoring: Architectural detail model is updated further for construction. (Essential BIM Use) 5. Cost estimating: 5D cost estimating is created via quantity take off from the model. (Enhanced BIM Use) 6. Phase and 4D planning: 4D planning is prepared to plan construction sequence effectively. (Enhanced BIM Use) 7. Engineering analysis: Energy analysis is conducted based on the model to asses building energy performance. (Enhanced BIM Use) 8. Sustainability analysis: Sustainability/LEED evaluation is performed based on the model. (Enhanced BIM Use) 9. Tender documents including BIM protocols are created.

Figure 7 Mapping from BIM outcomes to Base practices

BIM PRM is derived from Building RPM, and created to define BIM related building processes in terms of BIM. Therefore, Building PRM can be considered as an intermediary step to BIM PRM. In other words, BIM PRM is a subset of Building PRM as presented in Figure 7. Definitions of processes in BIM PRM would have been incomplete, if we developed the BIM PRM without considering the traditional AEC/FM processes. Processes are visualized as the elements of the sets as given in Figure 8.

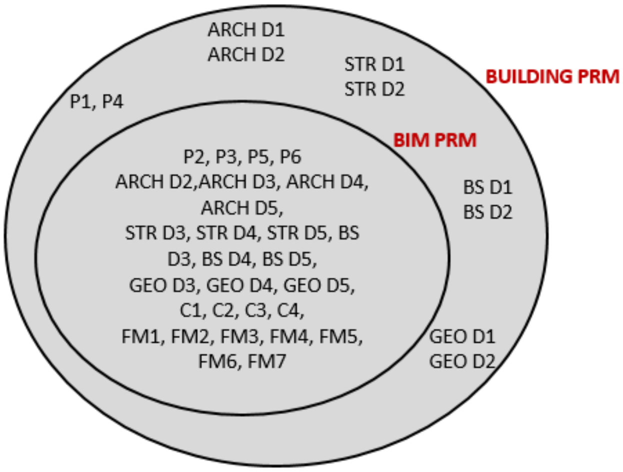

Figure 8 Relationship between Building PRM and BIM PRM

Twenty-eight BIM related processes are defined in total. Definitions of all BIM related AEC/FM processes' in BIM PRM are given in Appendix B.

3.1.2 *BIM Measurement Framework*

For the development of the second part of BIM-CAREM, which is BIM MF, the standards namely ISO/IEC 33003 – Requirements for Process Measurement Frameworks (ISO/IEC, 2015c) and ISO/IEC 33020 – Process Measurement Framework for Assessment of Process Capability (ISO/IEC, 2015) are taken as basis. Details of the standards are explained in Section 2.4.2.

Followed research tasks, which are presented in Figure 4, for theoretical development of BIM MF are as follows:

1. Identifying BIM uses from literature,
2. Finding recurring keywords in BIM uses via Natural Language Analysis,
3. Clustering BIM uses in terms of recurring keywords,
4. Identifying and defining BIM Capability Levels and associated BIM Attributes,
5. Identifying and defining BIM Attribute Outcomes, Generic BIM Work Products and Generic Resources, and
6. Defining a Rating Scale

A BIM Capability Level indicates an organization's BIM leverage capability in their AEC/FM processes and is characterized by BIM attributes. A BIM Attribute is an observable phenomenon to be measured for identifying BIM capability level of an organization in formal assessments. A BIM Attribute Outcome is the observable result of a BIM attribute achievement. Generic Practice is the activity that contributes to the achievement of a BIM attribute. Generic BIM Work Product is a BIM artefact associated with the execution of a process. Generic Resource is resources which are required for executing a process. Rating Scale is a rating schema to be used in BIM capability assessments for identify the degree of achievement of BIM attributes. Four-point ordinal rating scale is developed within the context of BIM-CAREM.

First of all, it is required to decide how many capability levels are required for representing BIM utilizations of AEC/FM organizations without omitting any BIM usage. Different number of levels are created for different BIM capability and maturity models as presented in Table 5 in Section 2.2.10. For example, while six levels are defined in NBIMS's BIM CMM (NBIMS, 2015e), five levels and four levels are defined for BIM Maturity Matrix (Succar, 2010) and UK's BIM Maturity Levels (BIM Industry Working Group, 2011), respectively. It has been observed that four staged models have been proposed and tested most frequently (King & Teo, 1997). Additionally, we found that four-levels of BIM capability is found to be sufficient without omitting any significant type of BIM utilization in AEC/FM industry. Therefore, we created four levels of BIM capability for BIM-CAREM.

BIM Capability Levels and associated BIM Attributes are created simultaneously, and later, they are improved iteratively. For generating conceptual BIM Capability Levels and BIM Attributes, we took ISO/IEC 33020 (ISO/IEC, 2015) as a baseline. We also needed to identify what the most recurring and popular BIM uses are within the AEC/FM industry. Therefore, we first identified BIM uses from various resources such as the surveys, BIM Execution Plans (BEP), BIM guidelines and research articles. The resources, which are used for identification of BIM uses, are listed as follows:

- Green BIM – How BIM is Contributing to Green Design and Construction (McGraw Hill Construction, 2010a),
- Information Mobility – Improving Team Collaboration Trough the Movement of Project Information (McGraw Hill Construction, 2013),
- The Business Value of BIM for Construction in Major Global Markets – How Contractors Around the World Are Driving Innovation with BIM (McGraw Hill Construction, 2014b),
- SmartMarket Brief: BIM Advancements No.1 (McGraw Hill Construction, 2014a),
- The Business Value of BIM for Owners (McGraw Hill Construction, 2014c),
- Measuring the Impact of BIM on Complex Buildings (McGraw Hill Construction, 2015),
- NBS National BIM Report 2015 (NBS, 2015),
- NBS National BIM Report 2016 (NBS, 2016),
- BIM Project Execution Planning Guide created by the Pennsylvania State University (The Pennsylvania State University, 2011), and
- The Perceived Value of BIM in U.S. Building Industry (Gerber & Rice, 2010).

BIM uses, which are identified from each resource, are collected in an excel workbook and duplicates are eliminated. As presented in Table 15, total number of the BIM uses is 268. BIM use counts with respect to each resource are presented in Table 15.

Table 15 BIM use counts

Source	Number of BIM Uses
BIM Project Execution Planning Guide	22
NBS National BIM Report 2015 and 2016	9
Green BIM	22
Smart Market Brief: BIM Advancements	25
Information mobility	67
The Business Value of BIM for Construction in Major Global	58
The Business Value of BIM for Owners	9
Measuring the Impact of BIM on Complex Buildings	35
The Perceived Value of BIM in U.S. Building Industry	21
Total	**268**

Although we eliminated the syntactically same BIM uses, semantically same BIM uses have remained in the list. Therefore, Natural Language Analysis is used to identify recurring nouns and verbs in BIM uses. In software engineering, Natural Language Analysis (Bruegge & Dutoit, 2010) (Abbott, 1983) is an intuitive set of heuristics for generating a list of initial candidate objects, attributes and associations from short descriptions and requirements specification. Recurring nouns and verbs in BIM uses are identified by using RapidMiner (RapidMiner, n.d.). Identified keywords are presented in Table 16. Semantically same BIM uses are listed under the related keywords. The complete list of BIM uses with clustering can be found in Appendix D. Later, these keywords and the clustered BIM uses are used for development of BIM Capability Levels, BIM Attributes and Generic Resources in BIM MF.

Table 16 Recurring keywords utilized for development of BIM Capability Levels and BIM Attributes

Keyword	No of Occurrences
Team	11
Collaboration	9
Access	9
Share	8
Communicate	4
Interoperable	3
Training	3
Customization	2

BIM Capability Level 0 and Capability Level 1 is defined as Incomplete and Performed BIM based on ISO/IEC 33020 (ISO/IEC, 2015). For Level 0, no BIM Attributes are defined since BIM is not implemented or partially implemented in an AEC/FM organization at this level. For Level 1, two BIM Attributes are defined. One of the BIM attributes is “Performing BIM” which is given as a requirement in ISO/IEC 33003 standard (ISO/IEC, 2015c). The second BIM Attribute is BIM Training since "training" keyword, which is found as a frequent keyword in BIM uses as in Table 16, is another important criterion for using BIM effectively in organizations.

For BIM Capability Level 2, "collaboration" and "interoperability" are seemed to be two important criteria for integrating facility life cycle processes to each other by using BIM. Therefore, "BIM Collaboration" and "Interoperability" are defined as BIM Attributes of BIM Capability Level 2.

Lastly, for Level 3, BIM Attribute "Corporate-wide BIM Deployment" is created as a result of expert reviews and BIM Attribute "Continuous BIM Improvement" is created based on the key word "Customization" in Table 16.

Definitions of each BIM Capability Level and the associated BIM Attributes are created by looking at process capability definitions in ISO/IEC 33020 (ISO/IEC, 2015). BIM Capability Levels and their BIM Attributes of BIM-CAREM are explained as below.

- <u>BIM Capability Level 0 - Incomplete BIM:</u> The BIM is not implemented or it is partially implemented and fails to achieve the BIM outcomes.
    - There are no available BIM Attributes.
- <u>BIM Capability Level 1 - Performed BIM:</u> The BIM is implemented to achieve the process purpose and used for performing base practices and producing standalone BIM outcomes. However, BIM has not been integrated into facility life cycle phases and there are no significant BIM based collaboration and data exchange between the facility life cycle phases and the processes.
    - <u>BIM Attribute 1.1 Performing BIM</u> is a measure of the extent to which the defined BIM outcomes are achieved.
    - <u>BIM Attribute 1.2 BIM Skills</u> is a measure of the extent to which the organization prefer to work with BIM trained and/or BIM experienced employees.
- <u>BIM Capability Level 2 - Integrated BIM:</u> The previously performed BIM is now implemented using an integrated BIM capable of enabling collaboration between the project stakeholders and data exchange throughout the facility life cycle phases and the processes.
    - <u>BIM Attribute 2.1 BIM Collaboration</u> is a measure of the extent to which the BIM is used to support the collaboration and information exchange between the facility life cycle phases and the processes.
    - <u>BIM Attribute 2.2 Interoperability</u> is a measure of the extent to which interoperability and flexible data exchange between BIM software applications are supported.
- <u>BIM Capability Level 3 - Optimized BIM:</u> The previously integrated BIM is now used at the enterprise level and is continuously improved to support organizations' business goals.

- BIM Attribute 3.1 Corporate-wide BIM Deployment is a measure of the extent to which BIM is diffused to each of the facility life cycle phases and the processes and embraced by all team members.

- BIM attribute 3.2 Continuous BIM Improvement is a measure of the extent to which changes to the BIM practices are planned from analysis of common causes of variation in BIM usage, and from investigations of innovative BIM approaches for the deployment of BIM.

In order to enable operationalization of BIM capability assessments, users and assessors require to observe achievement of the BIM attributes through objective evidences. Therefore, observable measures which are Generic Practices, BIM Attribute Outcomes, Generic BIM Work Products and Generic Resources are developed based on the ISO/IEC 15504-5 (ISO/IEC, 2006).

For development of Generic BIM Work Products and Generic Resources, BIM handbook (Eastman et al., 2011), keywords identified from BIM uses which is given in Table 17, and twelve different BIM guidelines are used.

Table 17 Recurring keywords utilized for development of Generic Resources

Keyword	No of Occurrences
Device	9
Format	8
2D/Drawing	7
Software	6
Cloud	5
Policy	2

These twelve BIM guides are as follows;

- Los Angeles Community College District (LACCD) BIM Standards for Design-Bid Build Projects (BuildLACCD, 2009),
- New York District U.S. Army Corps of Engineers Official Manual for BIM Projects (U.S. Army Corps of Engineers, 2009),
- State of Ohio BIM Protocol (State Architect's Office, 2010),
- The VA BIM Guide (Department of Veterans Affairs, 2010),
- AEC Canada BIM Protocol (CanBIM Designers Committee, 2012),
- Singapore BIM Guide v2 (Building and Construction Authority, 2013),
- University of Southern California BIM Guidelines (USC Capital Construction Development and Facilities Management Services, 2012),

- GSA Building Information Modeling Guide Series 01 – Overview (GSA, 2007),
- Norway Statsbygg BIM Manual 1.2.1 (Statsbygg, 2013),
- Georgia Tech BIM Requirements and Guidelines for Architects, Engineers and Contractors (Georgia Institute of Technology, 2016),
- IU BIM Guidelines and Standards and Standards for Architects, Engineers, and Contractors (Indiana University, 2015), and
- Common BIM Requirements – General Requirements (The Building Information Foundation RTS, 2012).

For BIM Attribute 1.1 Performing BIM, Generic BIM Work Products such as 3D models, quantity takeoffs, are defined as assessment indicators which show that process is being performed by using BIM. Additionally, Generic Resources such as BIM authoring tools (Autodesk Revit (Autodesk, n.d.), Tekla Structures (Trimble, n.d.), etc.) are defined. For BIM Attribute 1.2 BIM Skills, Generic BIM Work Products such as BIM training budgets, BIM certifications of employees, and Generic Resources such as BIM consultancy are defined as evidences of achievement of BIM Skills BIM attribute.

For rating the achievement of BIM Attribute 2.1 BIM Collaboration, Generic BIM Work Products such as BIM execution plans, customized standards, and generic resources such as collaboration tools (Autodesk Vault (Autodesk, n.d.-b)), usage of common data environments, are defined. For BIM Attribute 2.2 Interoperability, Generic BIM Work Products and Generic Resources such as interoperable formats (Industry Foundation Classes (IFC), XML, and etc.) are defined as indicators.

For BIM Attribute 3.1 Corporate-wide BIM Deployment, Generic BIM Work Products such using model in construction site, synchronization of model, libraries of custom BIM objects, and Generic Resources such as devices (tablets, sensors, etc.), international standards (Model View Definitions, etc.) are defined as assessment indicators. For BIM Attribute 3.2 Continuous BIM Improvement, Generic BIM Work Products such as strategies for BIM improvement, innovation meetings, and Generic Resources such as project management tools are defined as assessment indicators.

BIM Capability levels, related BIM Attributes, BIM Attribute Outcomes and example Generic BIM Work Products are summarized in Figure 9. Full content of the measurement framework of BIM-CAREM namely BIM MF can be found in Appendix C.

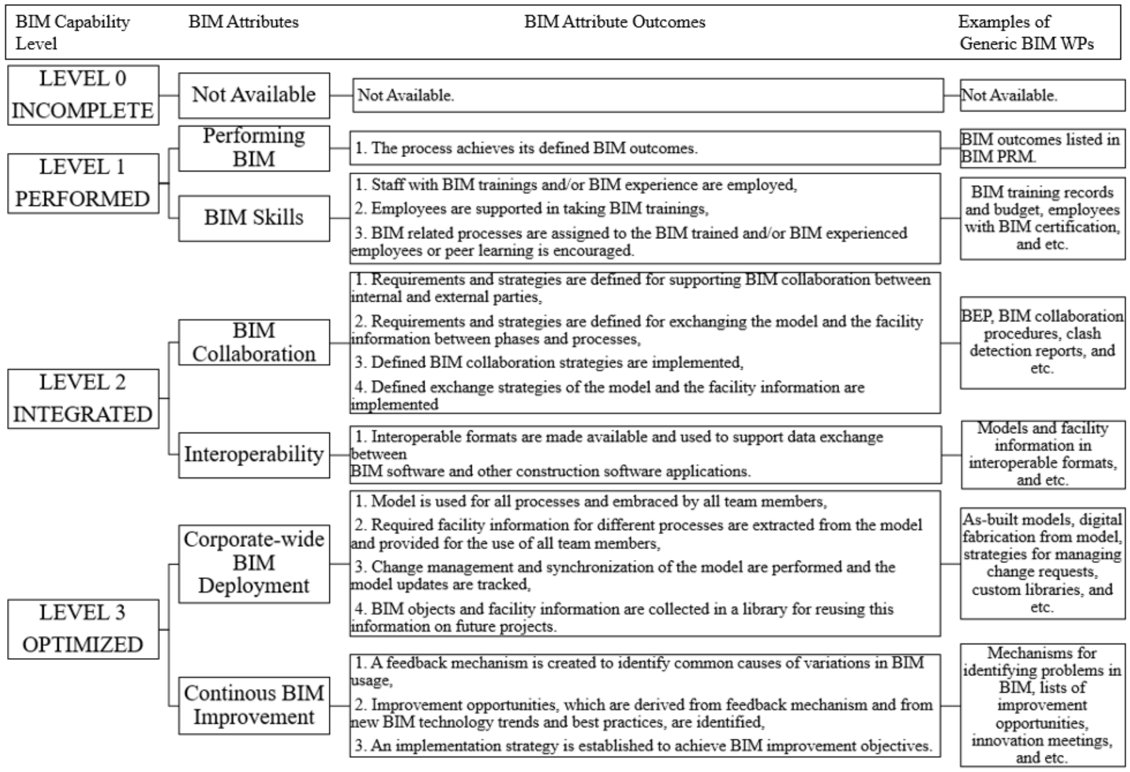

Figure 9 BIM Capability Levels, BIM Attributes and BIM Attribute Outcomes

Lastly, four point ordinal rating scale is defined based on the ISO/IEC 33020 (ISO/IEC, 2015). BIM attributes are rated against four points which are as follows:

- (N) Not Achieved: There is little or no evidence of achievement of the defined BIM attribute in the assessed process.
- (P) Partially Achieved: There is some evidence of an approach to achieve the defined BIM attribute in the assessed process.
- (L) Largely Achieved: There is evidence of systematic approach to achieve the defined BIM attribute in the assessed process.
- (F) Fully Achieved: There is evidence of a complete and systematic approach to achieve the defined BIM attribute in the assessed process.
- (N/A) Not Applicable: There is not enough evidence to assess the defined BIM attributes in the assessed process.

In order to have composite rating we aggregated the single ratings of BIM attribute outcomes. First, ordinal ratings F, L, P, N are converted into interval values 3, 2, 1, 0, respectively. Later, median of the single ratings are calculated. If there is odd number of values, the result is the middle value. On the other hand, if there is even number of values, the minimum of the two middle values is selected. The final result is converted back to the corresponding ordinal value. The achieved BIM Capability Level is derived according to the ratings of the BIM attributes as presented in Table 18.

Table 18 BIM capability level ratings of BIM-CAREM

Cap. Level \ BIM Att.	BIM A1.1 Performing BIM	BIM A1.2 BIM Skills	BIM A2.1 BIM Collaboration	BIM A2.2 Interoperability	BIM A3.1 Corporate-wide BIM Deployment	BIM A3.2 Continuous BIM Improvement
L0 - Incomplete						
L1 - Performed	L / F	L / F				
L2 - Integrated	F	F	L / F	L / F		
L3 - Optimized	F	F	F	F	L / F	L / F
L / F – BIM attribute is required to be achieved Largely or Fully. F – BIM attribute is required to be achieved Fully.						

3.2 Iterative Development of BIM-CAREM

Preliminary version of BIM-CAREM, which is BIM-CAREM-1, provided a point of departure for further modifications of BIM-CAREM. Figure 10 presents the evolving process of BIM-CAREM. In the first iteration, BIM-CAREM-1 is reviewed by one expert. BIM-CAREM-1 is modified based on the feedbacks, and BIM-CAREM-2 is created. In the second iteration, BIM-CAREM-2 is reviewed by two experts and tested by means of an exploratory case study. BIM-CAREM-2 is modified based on the feedbacks and findings, and BIM-CAREM-3 is created. In the approval phase, BIM-CAREM-3 is reviewed by two experts. BIM-CAREM-3 is approved based on the feedbacks, and final version of BIM-CAREM is prepared. Later, final version of BIM-CAREM is tested in four different Turkish AEC/FM companies by means of multiple case studies as explained in Section 4.4.

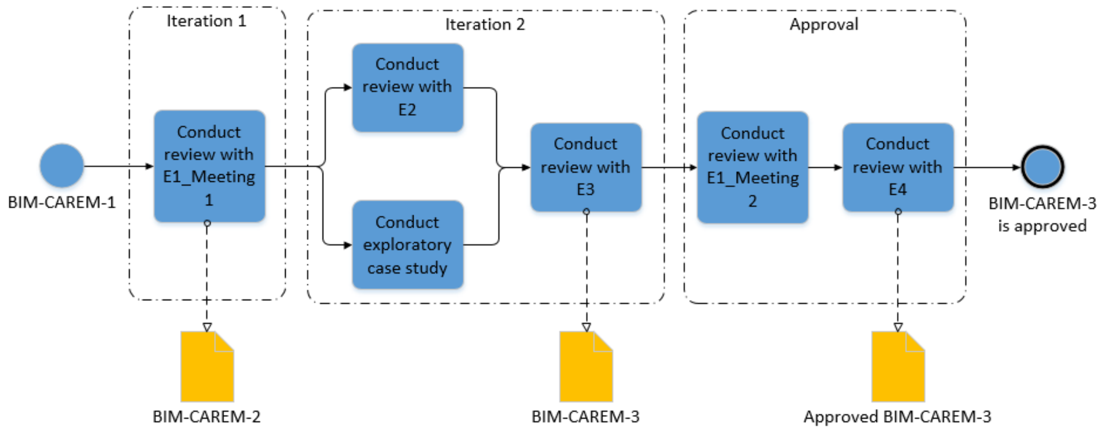

Figure 10 Evolving process of BIM-CAREM

While expert reviews are explained in this Section, exploratory case study is explained in Section 4.3. We have conducted five expert reviews with four different BIM experts. Two of the BIM experts are BIM consultants giving consultancies to AEC/FM firms in Turkey and Canada. One of them is the director of design and engineering team of a Turkish renowned constructor. Fourth expert is a civil engineering working in a renowned company in Turkey and previously worked as a BIM consultant in the United Kingdom. Experts and their titles are given in Table 19.

Table 19 Experts and their titles

Experts		**Title**
E1	Expert 1	Director of design and engineering team of an airport construction and operation company and has a PhD in Structural Engineering
E2	Expert 2	Architect and BIM consultant of the renowned AEC/FM firms in Turkey
E3	Expert 3	Mechanical engineer and BIM consultant of the renowned AEC/FM firms in Turkey and Canada
E4	Expert 4	Civil engineer who has an MSc in Construction Management and worked as a BIM consultant in the UK

Structure of BIM-CAREM and its parts are presented to the experts during each interview and their feedbacks are gathered by conducting semi-structured interviews. At the end of each meeting, we also asked each expert to rate BIM Attributes and their associated BIM Attribute Outcomes with one of the values; 1 - Not Essential, 2 - Important but not Essential, and 3 - Essential. After analyzing the feedbacks and the ratings, required changes are made on BIM-CAREM within the two iterations and the approval phase. The biggest modification is made on the BIM-CAREM-1 in the first iterative phase which caused creation of BIM-CAREM-2, as presented in Figure 10.

Interview details, gathered feedbacks and actions taken for updating the versions of BIM-CAREM are explained in Sections 3.2.1, 3.2.2 and 3.2.3 which are reviews towards first iteration, reviews towards second iteration and reviews towards approval of BIM-CAREM, respectively. In Section 3.2.4, experts' ratings for the BIM Attributes and BIM Attribute Outcomes are presented.

3.2.1 *Expert Review 1 for Creating BIM-CAREM-2*

BIM-CAREM-1 is presented to E1. The feedback is noted down and voice recording is taken during the interview. Later, collected data is analyzed and important feedback is determined. BIM-CAREM-2 is created by making required changes on BIM-CAREM-1. E1 is the director of the design and engineering team of a construction company which constructs and operates airports in various regions of the world.

Two hours meeting was held with E1. In this meeting, BIM-CAREM-1, which is the first version of the model, was explained to E1 and feedbacks were received. After analyzing the collected feedbacks, required changes are made on BIM-CAREM-1.

The first important point made by the expert was the need for clarifying the terminology used in the model. According to this feedback, terms used in the model are defined clearly and new terms are included in the model. Feedbacks regarding to each BIM Capability Level, associated BIM Attributes and BIM Attribute Outcomes are explained below under the related titles.

BIM Capability Level 1 – Performed BIM:

BIM A 1.1 Performing BIM: E1 mentioned that an organization, that wants to use BIM effectively, needs to have the necessary infrastructure. An organization should pay attention to having the following basic elements:

- Adequate number of powerful workstations,
- Employees who have BIM skills and knowledge,
- Required BIM tools with licenses, and
- Allocation of BIM related roles in company's organizational chart.

The above mentioned issues indicate that BIM is adopted and used by an organization effectively. Therefore, Generic Resources are defined for BIM A1.1 Performing BIM including the above issues such as adequate number of powerful workstations and having required BIM tools with licenses, and other construction software applications.

BIM A 1.2 BIM Skills: E1 also emphasized that an organization, which is using BIM, should support their employees in getting BIM trainings. An allocated BIM training budget within a company can show that employees are supported in taking BIM trainings. Additionally, BIM experience and BIM skills of professionals can affect the quality of the 3D models. Based on these feedbacks, we added BIM A1.2 BIM Skills for BIM Capability Level 1 – Performed BIM. Furthermore, a new BIM Attribute Outcome and a Generic BIM Work Product are defined for BIM A1.2 BIM Skills.

BIM Capability Level 2 – Integrated BIM:

BIM A 2.1 BIM Collaboration: One of the feedbacks of E1, was about creating BEPs. According to this feedback, if a BEP is created for a construction project, it means that details about BIM are considered and BIM goals/objectives are planned at the beginning of the project. We defined, BEP as one of the Generic BIM Work Products of BIM A2.1 BIM Collaboration.

BIM Capability Level 3 – Optimized BIM:

BIM A 3.1 Corporate-wide BIM Deployment: E1 mentioned that utilization of BIM in all facility life cycle phases and AEC/FM processes is one of the biggest targets of AEC/FM organizations. For example, it is very important to add the data coming from site into models. Additionally, a worker, who is working on site, must immediately be informed about a design change that an architect has made. Furthermore, it is very important that BIM should penetrate into all AEC/FM processes since professionals/employees use BIM for their own purposes. Based on the feedback, we inferred that organizations can have the most benefit of using BIM in AEC/FM processes when BIM enables integrating all AEC/FM processes in a construction project. Therefore, BIM A3.1 Corporate-wide BIM Deployment is added to BIM Capability Level 3 – Optimized BIM.

BIM Attribute Social Benefit is previously defined at BIM Capability Level 3 – Optimized BIM, where we wanted to measure the environmental, urban, and even social benefits of BIM. According to the feedback of E1, which is "It would not be possible to measure the social benefit of BIM from organizations' perspective", this BIM Attribute Social Benefit of BIM is taken out.

Furthermore, it is found that some of the expressions in BIM-CAREM, such as "Productivity is Improved", are very generic and it is difficult to determine whether such cases exist in AEC/FM organizations. General expressions like this are taken out from the model.

Generally, E1 stated that the model has a systematic approach for performing assessment and such a logical structure can create benefit for AEC/FM industry.

3.2.2 *Expert Review 2 and Expert Review 3 for Creating BIM-CAREM-3*

BIM-CAREM-2 is presented to E2 and E3. The feedback is noted down and voice recording is taken during the interview. Later, collected data is analyzed and important feedback is determined. BIM-CAREM-3 is created by making required changes on BIM-CAREM-2. Details of Expert Review 2 and details of Expert Review 3 are explained under the related titles.

Expert Review-2: E2 is an architect and BIM expert who gives BIM consultancies to various AEC/FM firms. One and half hours of meeting is held with E2. We started with reviewing the BIM PRM. Feedback regarding the BIM PRM and each BIM Capability Level, associated BIM Attributes and BIM Attribute Outcomes are explained below under the related titles.

BIM Process Reference Model: Architectural global and architectural detail design processes are reviewed carefully. Moreover, E2 gave recommendations for all of the processes in BIM PRM.

E2 mentioned the differences between design tools and BIM authoring tools. For example, Rhino is not a BIM design authoring tool but an advanced design authoring tool which is usually preferred for designing stadiums. E2 mentioned that the main goal of BIM is to help reduce facility information loss as project moves from design phase to construction phase. Towards this end, BIM should be included as early as possible in design phase. Additionally, E2 mentioned that there are iterations in design and the design should be transformed into a real facility in one of these iterations.

In BIM PRM, the term “High Level Precision” is removed from BIM Outcomes, since it does not tell us how much information is included in these outcomes. An example of previously defined BIM Outcome, which contained this term, is “5D cost estimation is created to a high level of precision”. By keeping this point in mind, each process in BIM PRM is reviewed and updated.

Again, in BIM process reference model, the expressions such as model of spaces, model of facades, and model of external structures are removed since these elements belong to a building and they are not included in other types of facilities. General statements are used for covering other types of facilities.

Additionally, it was suggested that terminology of the model should be corrected. For example; E2 suggested that “BIM software” should be replaced with “BIM design authoring tool” and “production” should be replaced with “construction”. However, “BIM software” is not changed because not only generating 3D models, but also processes such as conducting engineering analysis and phase planning based on 3D models are covered with the term “BIM software”. On the other hand, term “production” is replaced with “construction”.

E2 proposed to cluster BIM outcomes based on the two values which are “High BIM Use” and “Medium BIM Use”. According to this feedback, we found out a recent publication namely National BIM Guide for Owners (2017) which clusters BIM uses based on the two values namely “Enhanced BIM Use” and “Essential BIM Use”. We used the same terminology and marked each BIM outcome with either “Essential” or “Enhanced BIM Use”. For example; two BIM Outcomes of the “Make Architectural Detail Design” are marked as follows:

- Design authoring: Architectural model is authored in detail. (Essential BIM Use)

- Cost estimating: 5D cost estimation is prepared via quantity take off from model. (Enhanced BIM Use)

We also identified BIM uses which are not listed in the National BIM Guide for Owners. WE have not uses any tag for these BIM uses in order to be consistent with the document. However, all BIM uses can be tagged in the future based on the requirements of the assessment and/organization.

<u>BIM Capability Level 1 – Performed BIM:</u>

<u>BIM A 1.2 BIM Skills:</u> E2 suggested to explain BIM skills more explicitly. For example, BIM knowledge level of an architect should be different than that of a site worker. We have not changed the definition of BIM A1.2 BIM Skills since we wanted to keep it generic and we imply BIM training of professionals such as an architect and civil engineer rather than a site worker. E2 recommended to give the responsibility of BIM management to the BIM manager of a company since each stakeholder in a construction project has different tasks.

<u>BIM Capability Level 2 – Integrated BIM:</u>

<u>BIM A 2.1 BIM Collaboration:</u> There are various kinds of stakeholders, such as designers, engineers, and site workers, in a construction project. For example, a labor working on site wants to view the model from her/his point of view. S/he wants to filter the information and visualize the parts specific to his task. E2 suggested us considering these issues/constraints of AEC/FM projects to include them into the model.

E2 suggested checking the BS 1192 – 4 Collaborative Production of Information: Fulfilling Employer's Information Exchange Requirements using COBie (BSI, 2014a) for defining BIM A2.1 BIM Collaboration. It has already been studied and used for development of BIM A2.1 BIM Collaboration.

E2 suggested looking at the BS 1192 – 2007 Collaborative Production of Architectural, Engineering and Construction Information (BSI, 2007) for BIM A2.1 BIM Collaboration. It has already been used during the development of BIM A2.1 BIM Collaboration.

One of the feedbacks of E2 is that information lost occurs in each phase of facility life cycle and the main goal of BIM is to reduce the amount of information loss. E2 gave an example that a facility manager can tell what information is required for FM and can give feedback for the design. But, facility manager cannot work with an architect or a civil engineer collaboratively. Therefore, E2 suggested giving another name for BIM A2.1 BIM Collaboration. This feedback is not implemented into the model since BIM Collaboration is an important criterion for enabling integration of different AEC/FM processes and more comprehensive in representing the communication between the stakeholders.

In general, E2 found the structure of BIM-CAREM logical. As an improvement suggestion, E2 said that "BIM-CAREM can give better assessment results, if it can be defined more close to the AEC/FM industry in real life".

Expert Review-3: E3 is a BIM consultant who gives BIM consultancies to international AEC/FM companies in Turkey and Canada. We made an interview which lasted for half an hour. Feedback regarding each BIM Capability Level, associated BIM Attributes and BIM Attribute Outcomes are explained below under the related titles.

As a BIM consultant, E3 said that they use checklists for conducting project-based gap analysis. These checklists are created from technical point of view for identifying gaps in the 3D models and BIM related problems in AEC/FM processes. By following the same strategy, E3 suggested us to create a checklist for using it during BIM capability assessments.

We have already developed a template in Excel, which is composed of pre-defined questions, to be used during BIM capability assessments. However, in addition to this, we created a checklist by using Generic BIM Work Products and Generic Resources of BIM attributes. We conducted BIM capability assessments in multiple case studies by using this checklist. It allowed us to give ratings to each BIM Attributes more objectively.

E3 suggested us to control if the term "level" is explanatory for different BIM utilizations. We did not make any change to the term "level", since we have developed BIM-CAREM based on the principles of ISO/IEC 33000 standards.

BIM Capability Level 3 – Optimized BIM:

BIM A 3.2 Corporate-wide BIM Deployment: According to E3, the BIM Attribute Outcome of BIM A3.1 Corporate-wide BIM Deployment, which is given below, is difficult to be measured. It can be applicable to a contractor but it is not valid for a design firm. It can be more meaningful if this BIM attribute is used for measuring BIM capability of a project. According to this review, we updated the BIM Attribute Outcome. The first and updated versions of the BIM attribute are as follows:

1. Previous version: Model is used from the initial phase to the final phase of the facility life cycle.

2. New version: Model is used for all processes and embraced by all team members.

This change made the BIM attribute outcome more generic. New version of the BIM Attribute Outcome is used to measure if all BIM related processes of the organization are performed by using BIM and if BIM is accepted by all users of the organization.

E3 made the same comment for the BIM Attribute Outcome "BIM objects and facility information are reused on future projects". According to E3, although having a BIM objects library is important for the firm, it is not very important for the projects. However, we have not made any changes to this BIM Attribute Outcome, since we believe that having a custom 3D object library is important both for the projects and for the companies to increase reusing of BIM information.

Generally, E3 emphasized that BIM-CAREM is a valuable and precious work and said that it would be better if the checklist and the possibility of conducting assessments based on either the project or the firm is added into the model.

3.2.3 *Expert Review 4 and Expert Review 5 for Approving BIM-CAREM3*

BIM-CAREM-3 is presented to E1 and E4. Feedbacks are noted down and voice recording is taken during the interview. Later, collected data is analyzed and important feedbacks are determined. A new version of BIM-CAREM isn't created, since we recognized that most of the given feedbacks were covered before. Therefore, any modification isn't made on BIM-CAREM-3 and BIM-CAREM-3 is approved. Details of Expert Review 4 and details of Expert Review 5 are explained under the related titles.

Expert Review-4: A second meeting is performed with E1. The interview lasted three hours. Feedbacks regarding to each BIM Capability Level, associated BIM Attributes and BIM Attribute Outcomes are explained below under the related titles.

Level 1 – Performed BIM:

BIM Attribute 1.1 Performing BIM: according to E1, one of the biggest problems of the AEC/FM companies is that they do not exactly define what their BIM outcomes are. Since BIM outcomes are defined in BIM PRM, conducting assessments in terms of BIM outcomes can create an advantage for the companies.

BIM Attribute 1.2 BIM Skills: According to E1, when a new employee is hired, peer learning is usually encouraged. Therefore, BIM Attribute Outcome, which is "BIM related processes are assigned to the employees who have BIM skills, experience and has taken BIM trainings", is not necessarily implemented in an organization. According to this feedback, we added the "peer learning" as part of this outcome. It turned out to "BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged.".

Level 2 – Integrated BIM:

BIM Attribute 2.1 BIM Collaboration: E1 suggested us to think about BIM Collaboration by looking from broader perspective rather than just focusing on the coordination. E1 mentioned about BIM Implementation Plan (BIP) which is mostly similar to BEP. According to this we revised the definition of BEP.

BIM Attribute 2.2 Interoperability: "Plugins" is added as a Generic BIM Work Product of this attribute.

Level 3 – Optimized BIM:

BIM Attribute 3.1 Corporate-wide BIM Deployment: E1 gave examples about carrying out non-construction tasks with BIM. For example, BIM tools can be integrated with non-construction software applications such as ERP, space management, cost management, contract management, and spare parts inventory. However, in order to exchange information effectively, standardization and tagging of the assets should be included in the tools properly.

According to E1, some of the problems occurring in the design still remain in the FM. For example, one of their customers wanted to have their assets to be linked to BIM. Tag labels were clearly given in the technical specification of the project. Therefore, they used this labelling format for linking the assets to BIM. However, later client wanted to change all of the labels of asset tags according to their own corporate-wide definitions. Based on this example, E1 suggested that company-wide BIM execution plans defining BIM objectives/goals and BIM usages within the company are required to be created. Since, it can be vague when BIM usages are not clearly defined. According to this feedback, we added a Generic Practice which is "Define company-wide BIM execution plan", for this BIM Attribute.

E1 suggested to change the term "deployment" with another term such as execution or implementation. However, term "deployment" is kept. The word "automatically" is removed from the BIM Attribute Outcome which is "Change management and synchronization of the model are established and the model updates are tracked automatically". The word "library" is added in BIM Attribute Outcome which is "BIM objects and facility information are collected in a library for reusing this information on future projects". According to one of the E1's feedback, Level of Development (LOD) and Level of Information (LOI) are included in BIM PRM.

Expert Review-5: E4 is a civil engineer and have an MSc degree in construction management. E4 have worked as consultant in a consultancy company in UK. E4 have worked as a consultant in a consultancy company in United Kingdom. She gave consultancies to international AEC/FM firms about the standards and regulations of UK's AEC/FM industry. We had one and half hour meeting with E4. Feedback regarding to each BIM Capability Level, associated BIM Attributes and BIM Attribute Outcomes are explained below under the related titles.

E4 suggested to include sub-contractor's points of view within BIM-CAREM. E3 gave a similar feedback about one of the BIM attributes of Corporate-wide BIM Deployment which is "Model is used from the initial phase to the final phase of the facility life cycle". E3 told that it is hard to measure this BIM attribute outcome in a design firm, but it can be more easy to measure it for a general contractor. Based on this E3's feedback, we updated this outcome, and it became "Model is used for all processes and embraced by all team members". Therefore, we solved the problem of covering different organizations' views. However, detailed requirements of sub-contractors can be specified and included in the model in future.

Level 1 –Performed BIM:

BIM Attribute 1.2 BIM Skills: E4 suggested to add the high level management support. Also, E4 emphasized that some employees can learn BIM during performing BIM tasks or working with others who already know BIM. Additionally, for some employees it might be adequate to be aware of BIM rather than having BIM skills. Therefore, according to E4, all employees are not required to take BIM training.

Level 2 – Integrated BIM: E4 suggested to define a new attribute Process Definition Capacity for Level 2. It means that how AEC/FM firms can adapt their defined process into different construction projects in different places/countries. This attribute is not added since, BIM A 3.2 "Continuous BIM Improvement" measures whether organizations create improvement paths regarding the BIM usages in their processes.

BIM Attribute 2.1 BIM Collaboration: E4 agreed with the BIM attribute outcome "Requirements and strategies are defined for supporting BIM collaboration between internal and external parties." However, E4 did not agree to have the BIM attribute outcome "Requirements and strategies are defined for exchanging the model and the facility information between phases and processes". According to E4, delivery methods can be flexible, and it is not required to be rigid. We did not make any changes in this BIM Attribute Outcome since in our view "definition of strategies for information exchange" does not imply rigidity.

Level 3 – Optimized BIM: Within the context of Level 3, E4 suggested to think about the points which are project based problem resolution, communication between existing processes and new BIM processes, and integration of BIM software with existing software applications. Project based problem resolution is addressed with BIM A3.2 Continuous BIM Improvement since benchmarking can allow professionals to create solutions based on historical data. Communication between existing processes and new BIM process is covered with the attributes which are BIM A2.1 BIM Collaboration, BIM A2.2 Interoperability, and BIM A3.1 Corporate-wide BIM Deployment. E4 suggested that document management systems can be added for this capability level. However, it is defined as a Generic Resource of BIM A 2.1 BIM Collaboration.

BIM Attribute 3.1 Corporate-wide BIM Deployment: E4 said that "All processes do not need BIM and BIM is not required by everybody in the organization. Ownership of the model is important. Someone can do very well with BIM but do not need to share.". We marked BIM related AEC/FM processes before. Thus, our focus is to assess the BIM capability of BIM related AEC/FM processes.

BIM Attribute 3.2 Continuous BIM improvement: E4 found this BIM attribute important and well defined.

3.2.4 *Results of the Expert Reviews*

At the end of each expert review, an online questionnaire is applied for gathering opinions about BIM Capability Levels, associated BIM Attributes, and BIM Attribute Outcomes of BIM MF. Each expert is asked to give a rating to each question from 1 to 3 points which are;

- Not essential (1 points),
- Important but not essential (2 points), and
- Essential (3 points)

Figure 11 presents the results of experts' answers for BIM Attributes. As depicted in Figure 11, BIM Attributes are representing the BIM Capability Levels. Only BIM A3.1 Corporate-wide BIM Deployment is rated as "Important but not essential" since its applicability to different firms such as a general contractor and a sub-contractor found to be different. Complete answers of expert reviews can be seen in Appendix E.

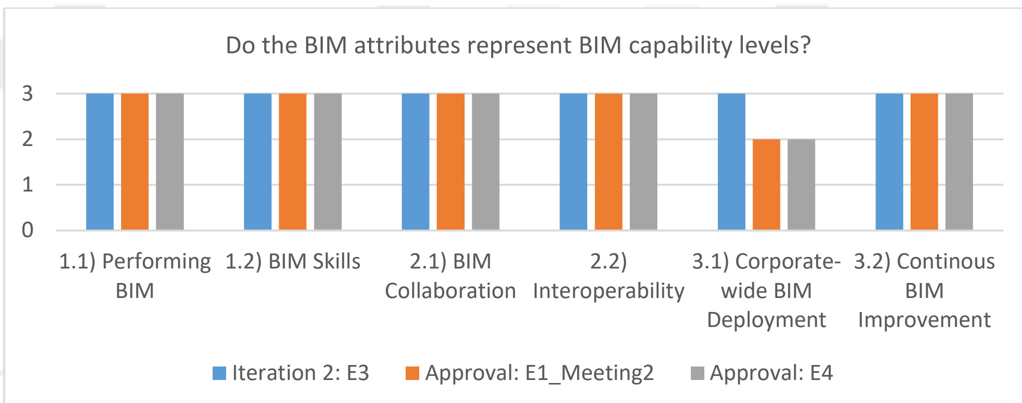

Figure 11 Ratings of experts for BIM attributes

Figure 12 presents the ratings of the experts for BIM Attribute Outcomes. As given in Figure 12, only BIM attribute outcomes "Model is used for all processes and embraced by all team members." and "BIM objects and facility information are collected in a library for reusing this information on future projects." are rated as "Not essential" by E3. Because, E3 emphasized the difference between assessing capability of BIM projects and AEC/FM organizations. According to E3's feedbacks, required changes are made on the model, and BIM-CAREM-3 is developed which is explained in Section 3.2.2.

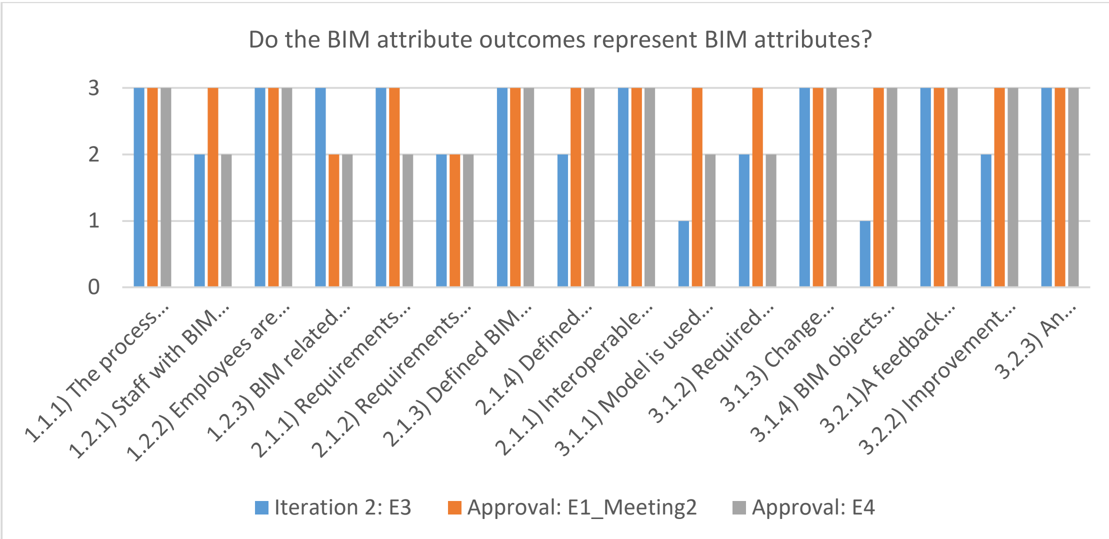

Figure 12 Ratings of experts for BIM Attributes Outcomes

CHAPTER 4

APPLICATION OF BIM-CAREM

This chapter presents the empirical testing of second and third versions of BIM-CAREM via exploratory case study and multiple case studies, respectively. Section 4.1 describes the observation process of a formal appraisal prior to the case studies. Section 4.2 describes the exploratory case study and multiple case studies. Multiple case studies are conducted to answer the research question RQ2 and its sub question RQ2.2.

4.1 Preparation for Exploratory Case Study and Multiple Case Studies

Prior to the exploratory case study and multiple case studies, an ISO/IEC 15504 software process assessment audit is observed. Six software processes, which are selected from the list of software processes given in ISO/IEC 15504-5 - An Exemplar Process Assessment Model (ISO/IEC, 2006), are assessed within the context of the appraisal. Each of them is defined in ISO/IEC 15504-5 in terms of process purpose, base practices, and process outcomes. These six software processes are:

1. ENG 1. Requirements elicitation,
2. ENG 4. Software requirements analysis,
3. ENG 5. Software design,
4. SUP 2. Verification,
5. SUP 9. Problem resolution management, and
6. SUP 10. Change request management.

Assessment of each process lasted approximately one hour, hence the assessment took six hours in total. This appraisal experience helped us to gain knowledge about the questions that should be asked and the indicators that should be observed for conducting a formal appraisal. It also helped us to understand which indicators create baseline for giving ratings to BIM attributes. Furthermore, we had opinion about data collection during an appraisal.

ENG 1. Requirements Elicitation is assessed within the context of the appraisal. The selected process is evaluated with respect to two capability levels which are Level 1 - Performed Process and Level 2 - Managed Process. Assessment details are explained by giving example questions and example assessment indicators.

During the assessment of Level 1- Performed Process, we asked questions to process owners to understand whether they are implementing Base Practices or not. Example Questions (Q) asked and example Assessment Indicators (AI) observed during the appraisal are given as follows:

Level 1 - Performed Process:

Process Attribute 1.1 Process Performance:

ENG.1.BP 1: Obtain customer requirements and requests:

- Q: How do the requirements come from customers?
- AI: Job descriptions and emails which include details about the communication with customers.

ENG.1.BP 2: Understand customer expectations:

- Q: Is there any other document created until the requirements specification comes from the customer?
- AI: Meeting notes of the customers and themselves.

ENG.1.BP 3: Agree on requirements:

- Q: Which document is sent to the customer for the approval?

ENG.1.BP 4: Establish customer requirements baseline:

- Q: How are the requirements specification baselined?
- AI: Job description documents, project activity plan such as work breakdowns and details of these work breakdowns and user interfaces, and software Requirements Specification (SRS).

ENG.1.BP 5: Manage customer requirements changes:

- Q: How do you track the customers' change requests? How do you manage them?
- AI: Definition of tasks to be performed for change requests, confirmation of cost estimations after revisions, approval of customer, revised SRS and different versions of SRS.

ENG.1.BP 6: Establish customer query mechanism:

- Q: Do you have a mechanism for customers to query?

For the assessment of Level 2 – Managed Process, questions are asked to understand whether they are implementing Generic Practices of the two process attributes which are Process Performance Management and Work Product Management. Assessment indicators were also collected by looking at example work products. Example questions and assessment indicators are given as follows:

Level 2 - Managed Process:

Process Attribute 2.1 Process Performance Management:

GP 2.1.1 Identify the objectives:

- Q: Do you have measurement targets for this process? Are there measurements for the analysis of the process within the scope of this project?

- AI: General approach for identifying objectives which is corporate wide but not process specific.

GP 2.1.2 Plan and monitor the performance:

- Q: Is there a period for FRS preparation? Is this time exceeded?

GP 2.1.3 Adjust the performance:

- Q: Do you take precautions if time is exceeded?

GP 2.1.4 Define responsibilities and authorities:

- Q: Are the roles defined?

- AI: Roles and responsibility matrix.

GP 2.1.5 Identify and make available resources:

- Q: What are the resources?

- AI: Jira which a software development tool for planning, tracking and releasing software

GP 2.1.6 Manage the interfaces:

- Q: Who is discussed with in the analysis process?

Process Attribute 2.2 Work Product Management:

GP 2.2.2 Define the requirements for documentation and control:

- Q: Has the FRS been reviewed?

GP 2.2.4 Review and adjust work products:

- Q: Are configuration management completed before the baseline?

Although the domain of the appraisal was software engineering, this observation was very useful in terms of understanding which questions should be asked and which evidences should be collected during a formal assessment.

4.2 Design of Exploratory Case Study and Multiple Case Studies

Single exploratory case study is carried out by using BIM-CAREM-2 and its objective is as follows:

- Investigating if BIM-CAREM requires any improvement before conducting the multiple case studies.

BIM-CAREM-3 is created based on the expert reviews, which are explained in Section 3.2, and the exploratory case study which is explained in Section 4.3. Later, final version of BIM-CAREM, which is BIM-CAREM-3, is tested via multiple case studies. Objectives of the multiple case studies are created according to the research question RQ2.2. The two objectives of the multiple case studies are as follows:

- Investigating the suitability of BIM-CAREM for assessing BIM capabilities of a AEC/FM process, and

- Identifying the strengths and weaknesses of BIM-CAREM.

Case selection strategy, data collection methods, validation strategy and data analysis methods are explained in the following sub-sections.

4.2.1 *Case Selection Strategy*

During the theoretical development of BIM-CAREM, we have carried out face-to-face interviews with the BIM manager of Company A for reviewing design processes in BIM PRM. They perform all design processes belonging to different disciplines which are Architectural, Structural, Building Services and Geotechnical Design. Therefore, Company A is selected to test the BIM-CAREM-2 within the context of the exploratory case study.

Six criteria are identified in order to select AEC/FM organizations for testing the final version of the BIM-CAREM. A number of Turkish AEC/FM organizations, that are fulfilling the criteria below, are included in the multiple case study. These criteria are as follows:

- Selecting organizations that are using BIM for performing their processes, but it is not necessary to have BIM as a contract requirement,

- Selecting different types of organizations such as designers and constructors,

- Selecting organizations with different organizational size,

- Including different facility types such as hospitals, stadiums, and airports,

- Including different structural frame types such as steel and reinforced concrete,

- Including at least one company for each facility life cycle stage, which are architectural, structural and building services design, construction, and facility management, and

- Selecting companies which are using BIM at different BIM capability levels.

According to these criteria, we have selected five different companies which are presented in Table 20. Company A is included in exploratory case study and the rest of the four companies are included in the multiple case studies.

Table 20 AEC/FM organizations included in the exploratory case study and the multiple case studies

Case Study No	**Company Name**	**Type and Size**	**Evaluated Project Type**	**Evaluated Frame Type**	**Assessed Phase**	**BIM Contract Req. (Y/N)**
Exploratory CS	Comp. A	Design and engineering firm with number of employees more than 200	Metro projects including tunnels, stations, etc.	Reinforced concrete	Conceptual Planning, Architectural, Structural and Building Services	Y
CS 1	Comp. B	Structural design firm with number employees less than 50	Sport facilities such as stadiums, buildings	Steel and Reinforced concrete	Structural Design	Y
CS 2	Comp. C	Design firm with number of employees less than 10	Buildings such as hotels	Reinforced concrete	Architectural Design	N
CS 3	Comp. D	International constructor, with number of employees more than 200 in Healthcare Investment Group	Hospitals	Reinforced concrete	Construction	Y
CS 4	Comp. E	International constructor with number employees more than 2500	Airports	Steel and Reinforced concrete	Architectural, Structural and Building Services Design, Construction, Facility Management	Y

All of the companies are performing their AEC/FM processes by using BIM. BIM is a contract requirement for all of the companies except for Company C. Three of them are design firms which are specialized in different disciplines and working on designing different building types. Two of them are general contractors. One of them is specialized in constructing hospitals, and the other general contractor works on constructing airports. Only Company E is performing facility management by using BIM.

We thought that including companies working on different project types would help us to understand the suitability of BIM-CAREM for use in the AEC/FM industry. Thus, we included companies which are working on different facilities such as hotels, metro tunnels, stadiums, hospitals and airports. Additionally, two kinds of structural frame types which are steel and reinforced concrete are evaluated.

4.2.2 *Data Collection Methods*

Primary data is collected by conducting formal assessments through semi-structured interviews with one or more interviewees who are architects, engineers, and BIM coordinators. Pre-defined questions are developed and stored in an excel sheet and this template is used for collecting answers of the interviewees. Excel based assessment template with pre-defined questions can be seen in Appendix F. We also got permission for voice recording prior to each case study in order to record the whole assessment process.

Secondary data is collected by performing direct observations since according to Yin (2003), direct observations enable to observe some relevant behaviors and environmental conditions. After exploratory case study, we understood that it is important to clarify what to observe during the case study. Thus, a checklist, is prepared according to Expert 3's feedback. This checklist includes assessment indicators which are Generic BIM Work Products and Generic Resources of each BIM Attribute. Hard copies of these checklists are taken to each assessment. Each indicator is controlled one by one and is ticked or not according to their existence. This is the applied procedure for the multiple case studies. Checklist can be found in Appendix H.

4.2.3 *Validation Strategy*

Findings and ratings are shared with interviewees. We clarified the findings by informal checks. Furthermore, and online questionnaire, which is given in Appendix G, is applied for validating the findings and ratings. Questionnaire is composed of five questions and the answers are collected in Likert scale (1-5). We asked the opinions of the interviewees about the findings and collected ratings of the assessment to validate the results.

4.2.4 *Data Analysis Methods*

Assessment reports are written based on the voice recordings, excel based assessment notes, and marked checklists. Assessment report is taken as a baseline to determine the BIM Attribute ratings for identifying BIM Capability Levels.

Based on the assessment reports, each BIM outcome/BIM attribute outcome is given one of the ratings of 3, 2, 1, and 0. These interval ratings are found by converting the ordinal ratings F (3), L (2), P (1), N (0). We used Not Applicable (N/A) when there is not enough evidence to assess the defined BIM attributes in the assessed process. In order to have composite rating for BIM attributes we aggregated the single ratings of BIM outcomes/BIM attribute outcomes. We calculated the median of the single ratings according to the procedures explained in Section 3.1.2. Basically, if there is odd number of value, the result is the middle value. If there are even number of values, the minimum of the two middle values is selected. The final result is converted back to the corresponding ordinal value. The achieved BIM Capability Level is derived according to the ratings of the BIM attributes as presented in Table 18 in Section 3.1.2.

4.3 Implementation of the Exploratory Case Study in Company A for Design

We applied the second version of BIM-CAREM (BIM-CAREM-2) in one organization. We describe the selection reason of Company A for the exploratory case study and the findings of the case study are below.

We asked pre-defined interview questions and filled the excel based assessment template to assess the BIM capability of conceptual planning, architectural, structural and building services design. Excel sheet, which includes rating of each BIM outcome/BIM attribute outcome, can be found in Appendix F. Secondly, assessment evidences such as models created by using Revit are collected. Moreover, voice recording of the whole interview is taken. Lastly, assessment report of the company is written based on the notes and the ratings in excel, notes about assessment evidences and the voice recording. We did not use checklist in the exploratory case study, since it is created as part of the second iteration of BIM-CAREM. Findings are discussed with the interviewees for clarification and the online questionnaire is applied to the interviewees for validating the findings and the ratings of the assessment. Questionnaire results are given in Section 4.5.

We used the four-point ordinal scale which is explained in Section 3.1.2. Not Achieved (N – 0 point), Partially Achieved (P – 1 point), Largely Achieved (L – 2 points), Fully Achieved (F – 3 points) and Not Available (N/A) are represented as “Red”, “Yellow”, “Blue”, “Green” and “Grey”, respectively. To achieve a BIM capability level, all BIM attributes associated with that level should be rated as L or F.

4.3.1 *Demographic Information*

Company A was founded in 1985. It is a group of four companies, including Engineering, Software, Computer, and Training Centre. The company has offices in three different geographical locations which are Ankara, Istanbul and Izmir. Although Ankara is the biggest office, BIM is adopted by the İstanbul office first. For this reason, we have conducted our case study in Istanbul office. Company A is a design and engineering firm which has about 10 years of experience in designing metro projects. There are more than 200 employees who are architects, engineers and technicians in all of the offices in total. The number of employees who have BIM skills and experience are estimated to be 5 in Izmir, 15 in Istanbul and 3 in Ankara. Company A is using BIM for about 5 years and BIM is a contract requirement in most of their metro projects.

During the theoretical development of BIM-CAREM, we have carried out a face-to-face interview with the BIM manager of Company A to review design processes in BIM PRM, since they perform all design processes belonging to different design disciplines such as Architectural, Structural, Building Services and Geotechnical Design. Therefore, Company A is selected to test the second version of BIM-CAREM within the context of the exploratory case study.

4.3.2 *Findings of the Assessment*

We have looked at 4 different projects in which the client was Istanbul Metropolitan Municipality. Three of the projects were metro lines in different districts of Istanbul and one was a funicular railway.

Facility life cycle stages, which are P – Conceptual Planning, ARCH D – Architectural Design, STR D – Structural Design, BS D – Building Services Design, are included in the context of the BIM capability assessments, since Company A use BIM in these stages. Processes of these stages, which are assessed within this case study, are as follows:

- P2 – Study/Define Needs,
- P3 – Study Feasibility,
- P5 – Develop BIM Execution Plan,
- P6 – Select and Acquire Site,
- ARCH D2 – Draw Up Program,
- ARCH D3, STR D3, BS D3 – Make Global Design
- ARCH D4, STR D4, BS D4 – Make Detail Design, and
- ARCH D5, STR D5, BS D5 – Do Design Tasks During Construction.

It was a three-hours meeting which is composed of semi-structured interview with the lead MEP designer and the BIM manager of the company. Ratings of BIM outcomes/BIM attribute outcomes are collected in excel sheet of Company A which can be found in Appendix F. Questionnaire results are given in Section 4.5.

BIM capability level of conceptual planning, architectural, structural and building services designs are determined based on the ratings of BIM attributes, which are presented in Table 23. Usage of BIM in conceptual planning is limited. Most of the BIM outcomes of the conceptual plan are rated as “Largely Achieved” in Figure 14. Therefore, even though the ratings of BIM Collaboration and Interoperability are given as “Fully Achieved” for conceptual planning, it is identified at BIM Capability Level 1-Performed which is presented in Figure 13. In order to be at Level 2, BIM outcomes of conceptual planning should have been rated as “Fully Achieved”. Since most of the practices of architectural, structural and building services design are performed by using BIM, Performing BIM of design stages are rated as “Fully Achieved” which is depicted in Table 23. Employees of Company A are supported for BIM trainings and they also take BIM consultancy from a BIM expert. Therefore, BIM Skills is rated as “Fully achieved” in Table 23. They use BIM for collaboration, especially in design stage, and interoperable formats are used in all assessed stages. Thus, BIM attributes BIM Collaboration and Interoperability are rated as “Fully Achieved” for all of the assessed phases. However, they do not use BIM at the enterprise level and there is not a systematic approach for continuous BIM improvement. That’s why, architectural, structural and building services design stages are found at BIM Capability Level 2-Integrated BIM which is presented in Figure 13.

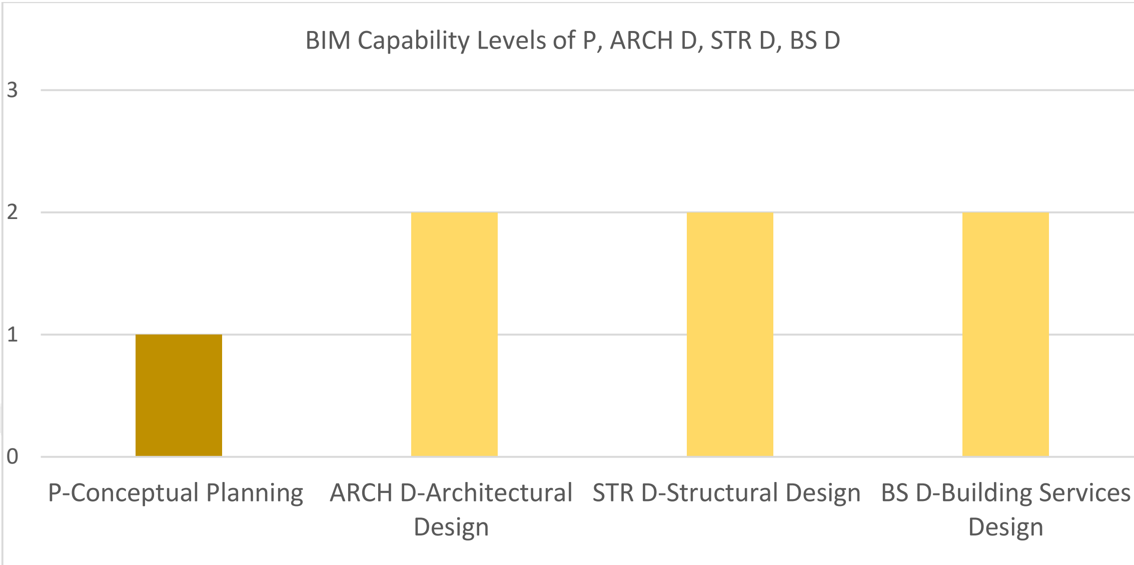

Figure 13 Achieved BIM capability levels of conceptual planning and architectural, structural and building services design for Company A

Final ratings of BIM Attributes with respect to conceptual planning, architectural, structural, building services design are presented as ordinal values (F, L, P, N) in Table 23. These ratings are derived from ratings of BIM outcomes/BIM attribute outcomes which are presented in Figure 14. Ratings of BIM outcomes/BIM attribute outcomes are aggregated for calculating the score of the associated BIM Attributes.

Table 21 BIM attribute ratings for Company A's conceptual planning, architectural, structural and building services design

Phase / BIM Attribute	Level 1-Performed BIM		Level 2-Integrated BIM		Level 3-Optimized BIM	
	BIM A1.1	BIM A1.2	BIM A2.1	BIM A2.2	BIM A3.1	BIM A3.2
P-Conceptual Planning	L	F	F	F	P	N
ARCH D-Architectural Design	F	F	F	F	P	N
STR D-Structural Design	F	F	F	F	P	N
BS D-Building Services Design	F	F	F	F	P	N

Based on the detailed assessment report of Company A, which is explained below, a rating is given to each BIM outcomes of the processes P2, P3, P5, P6, ARCH D2, ARCH D3, STR D3, BS D3, ARCH D4, STR D4, BS D5, ARCH D5, STR D5, BS D5 are given. Moreover, each BIM attribute outcomes of the BIM attributes are rated based on the assessment findings which are explained below. Ratings of BIM outcomes and BIM attribute outcomes are summarized in Figure 14 by using the color coding. Detailed ratings can be found in Appendix F. In Figure 14, interval values 3, 2, 1, and 0 are represented by "Green", "Blue", "Yellow" and "Red", respectively. Not Available (N/A) value is represented as the color "Grey". In order to find the composite rating value of each BIM attribute in Table 23, median values of the single BIM outcomes/BIM attribute outcomes ratings are taken by using the rules explained in Section 3.1.2. These median values of BIM outcomes/BIM attribute outcomes ratings are equal to the composite values of the BIM attributes that are given in Table 23.

<table>
<tr><th colspan="6">P/ARCH D/STR D/BS D-Architectural, Structural and Building Services Design</th></tr>
<tr><th colspan="4">BIM A1.1</th><th>BIM A2.1</th><th>BIM A3.1</th></tr>
<tr><td>P2-1</td><td>ARCH D2-1</td><td>STR D3-1</td><td>BS D3-1</td><td rowspan="5">BIM A2.1-a</td><td rowspan="5">BIM A3.1-a</td></tr>
<tr><td rowspan="3">P2-2</td><td>ARCH D2-2</td><td>STR D3-2</td><td>BS D3-2</td></tr>
<tr><td>ARCH D3-1</td><td>STR D3-3</td><td>BS D3-3</td></tr>
<tr><td>ARCH D3-2</td><td rowspan="2">STR D3-4</td><td>BS D3-4</td></tr>
<tr><td rowspan="3">P3-1</td><td>ARCH D3-3</td><td>BS D4-1</td></tr>
<tr><td>ARCH D3-4</td><td rowspan="4">STR D4-1</td><td rowspan="4">BS D4-2</td><td rowspan="6">BIM A2.1-b</td><td rowspan="6">BIM A3.1-b</td></tr>
<tr><td>ARCH D3-5</td></tr>
<tr><td rowspan="4">P5-1</td><td>ARCH D3-6</td></tr>
<tr><td>ARCH D3-7</td></tr>
<tr><td>ARCH D4-1</td><td rowspan="2">STR D4-2</td><td rowspan="2">BS D4-3</td></tr>
<tr><td>ARCH D4-2</td></tr>
<tr><td rowspan="4">P5-2</td><td>ARCH D4-3</td><td rowspan="2">STR D4-3</td><td rowspan="2">BS D4-4</td><td rowspan="4">BIM A2.1.c</td><td rowspan="3">BIM A3.1-c</td></tr>
<tr><td>ARCH D4-4</td></tr>
<tr><td>ARCH D4-5</td><td rowspan="2">STR D4-4</td><td rowspan="2">BS D4-5</td></tr>
<tr><td>ARCH D4-6</td><td rowspan="5">BIM A3.1-d</td></tr>
<tr><td rowspan="4">P6-1</td><td>ARCH D4-7</td><td rowspan="4">STR D5-1</td><td rowspan="4">BS D5-1</td><td rowspan="4">BIM A2.1-d</td></tr>
<tr><td>ARCH D4-8</td></tr>
<tr><td>ARCH D4-9</td></tr>
<tr><td>ARCH D5-1</td></tr>
<tr><th colspan="4">BIM A1.2</th><th>BIM A2.2</th><th>BIM A3.2</th></tr>
<tr><td colspan="4">BIM A 1.2-a</td><td rowspan="3">BIM A2.2-a</td><td>BIM A3.2-a</td></tr>
<tr><td colspan="4">BIM A 1.2-b</td><td>BIM A3.2-b</td></tr>
<tr><td colspan="4">BIM A 1.2-c</td><td>BIM A3.2-c</td></tr>
</table>

Figure 14 Ratings of BIM outcomes and BIM attribute outcomes

Ratings of each BIM outcome and BIM attribute outcomes are determined based on the assessment report of Company A. It includes the assessment findings and collected evidences for BIM outcomes and BIM attribute outcomes which are summarized below.

Level 1 – Performed BIM for P, ARCH D, STR D, and BS D:

BIM A 1.1 Performing BIM for P:

P2-1 User needs and requirements are defined regarding BIM usage in Design, Construction and FM phases: They usually have two types of projects which are Design-Bid-Build and Design-Build. In Design-Bid-Build, they usually start with a technical specification including customers' requirements and a previously created model/design. Furthermore, they prefer to keep the preliminary designs and make small changes on them. In Design-Build type of projects, there are only technical specifications and they create models from scratch by thinking the general contractors' and owners' point of views.

P2-2 Existing conditions modelling is conducted for a site/facilities on site/a specific area within a facility: They are performing existing conditions analysis with laser scanners. Model is created based on the point cloud data which is collected via laser scanners.

P3-1 Feasibility information (Economic, environmental and technical) is studied*:* Economic feasibility is investigated through Return on Investment (ROI). For example, economic feasibility studies include the issues whether the investment spent for building a metro line is returned by its operation, or not. Environmental feasibility includes the assessments related to the environmental impacts of buildings. For technical feasibility, they analyzed location of a metro line based on the amount of possible passengers. There are a number of software applications which simulates the movement of passenger in a metro station. These tools can be used for verification of technical feasibility. However, feasibility studies are carried out in dependent from BIM. Furthermore, they stated that since feasibility reports are approved by many governmental organizations, it is not clear if reports, which are created by using BIM tools, are valid for the governmental organizations.

P5-1 Define BIM as part of project delivery strategy and identify required BIM services: They usually have two types of projects which are Design-Bid-Build and Design-Build. In both of the delivery strategies, they identify BIM requirements. Even though the constructor usually is not determined in Design-Build projects, they create design by thinking about BIM requirements of the potential constructor.

P5-2 BEP is created: They create BEP for all of their projects. BEP is created based on the clients' technical specifications, and includes details about BIM. Later, BEP is sent to the customer for approval.

P6-1 Site analysis is conducted to determine the most optimal site location: They usually create models according to the ground conditions. In some of their projects, they changed the building type in accordance to the ground conditions.

BIM A 1.1 Performing BIM for ARCH D, STR D, and BS D:

They started to use BIM first in architectural design and later BIM is adapted to other disciplines which are structural and building services design. For this reason, the characteristics of BIM usage was mostly the same in all disciplines.

ARCH D2-1 Draw up space program and requirements are developed (areas, volumes and etc.): They develop space program and requirements based on technical specifications document which is sent by the client. BIM is not included in this process.

ARCH D2-2 Programming is conducted to assess design performance in terms of spatial requirements*:* They assess spatial performance by using BIM. For example, they assessed spatial performance of a room which is designed for electro mechanics infrastructure. They examined if this room meets specific requirements. Moreover, they also analyzed if stations are sufficient for passenger circulation.

ARCH D3-1, ARCH D3-2, ARCH D3-3, ARCH D4-2, ARCH D4-4, STR D3-1, STR D3-4, STR D4-1, BS D3-1, BS D3-4, BS D4-1 Design authoring: Autodesk Revit is used for architectural, structural and MEP design authoring. Architectural design is created based on technical specifications document which is sent by the client. Project starts with creating the architectural design. Design work flow is composed of four steps which are 1-Concept Design, 2-Preliminary Design, 3-Detailed Design, and 4-Constrcution Documents. When architectural design is completed, it is shared with other design disciplines including building services and structural design teams for their design authoring purposes. In most of their project they start with detailed design since they receive architectural design included in the tender documents when they are awarded the project. There are differences between the detailed design and the construction documents. For example, while channel dimensions are unclear in the detailed design, they are clear in construction documents. For example, the channel dimensions are real in construction documents of mechanical design. However, they have the dimensions from approvals in detailed design. Details are not modelled in detailed design. For example, there are not any information related to the issues such as if the shafts are reachable and if users can go under the platform. A detailed building services model is analyzed during the meeting. Models include parametric intelligence and are created by using Autodesk's design authoring tools.

ARCH D3-4, ARCH D4-3, STR D3-3, BS D3-2, BS D3-3, BS D4-2 3D coordination: They are conducting interference check by using built-in categories of Revit. These interference checks are performed by each design discipline team to eliminate internal conflicts. After that, models of all disciplines are coordinated by using Navisworks, which is a clash detection tool. A clash detection report stored in various formats such as .html, .xml, and clash test viewpoints is analyzed during the coordination meetings. They also import clash detection reports collected from different stakeholders into Navisworks.

ARCH D4-5, STR D4-3, BS D4-3 Cost estimating: A quantity takeoff example in Revit is observed during the interview. Their clients can demand the quantity take offs in different units such as length (m) and volume (m^3). Therefore, they created family trees in Revit to get quantity take off automatically in different units. While creating this sub-structure they also considered the 4D simulation and phase planning. They thought about the level of detail of the objects in Revit to be able to connect these objects with the activities in work schedules.

ARCH D4-6, STR D4-4, BS D4-4 Phase and 4D planning: They are using TimeLiner which is a Navisworks tool for creating simulations. After work plan is created, it is matched with all objects of the model to create the simulations.

ARCH D4-7, STR D4-2, BS D4-5 Engineering analysis: Electric engineers are usually conducting lightening analysis by using the electrical model. They are not doing energy analysis. However, the sub-structure of their models can support energy analysis if it is required. They are conducting Coupled Fire/Evacuation (CFD) analysis related to fire hazards in stations. This analysis is conducted based on the architectural model. In one of their projects, they investigated relationships between viaducts and its environment. They also perform structural analysis in structural design.

ARCH D4-8 Sustainability analysis*:* They looked at the sustainability by using Infraworks. They are not conducting LEED analysis. They are not doing energy analysis.

ARCH D4-1 Design review: Design review is conducted by using BIM authoring tools.

ARCH D3-5 Code and compliance checking is performed, and ARCH D3-7 An application for a building permit is submitted: Since they usually work with Istanbul Metropolitan Municipality, code validation and application for building permits usually done by the owner/general contractor in most of their project.

ARCH D4-9 Tender documents including BIM protocols are created: They usually work with other design offices for building services design. They specify their BIM requirements and create BIM protocols for tenders. When they select their design offices, they transfer the customer's technical specifications document to the design offices. They also send the architectural design in BIM to their building services design offices.

ARCH D5-1, STR D5-1, BS D5-1 Record modelling: Change requests from site are received in excel format. Based on this, they update models and create As-Built models. The change requests from the site are received via e-mail in excel formats.

BIM A 1.2 BIM Skills:

a) Staff with BIM trainings and/or BIM experience are employed,

b) Employees are supported in taking BIM trainings, and

c) BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged

They gave job advertisement to employ BIM skilled professionals. Peer learning is encouraged within the design teams. For example, it is encouraged by putting together the employees who have experience in metro projects and the employees with BIM knowledge. They have been taking consultancies from a BIM expert for two years. They usually ask questions to the BIM expert when they face with problems related to BIM in their projects. Although they do not have an allocated budget for BIM trainings, employees are sent to BIM trainings regularly. Since, one of their group-company is the Autodesk Gold Partner trainer in Turkey, employees took trainings related to various topics such as BIM, Revit, and Navisworks. BIM skilled employees are assigned to the important BIM roles in the beginning of the new projects. Attitude of the higher level management of the company is to achieve a certain level of BIM in the offices in all three locations which are Istanbul, Ankara and Izmir.

Level 2 – Integrated BIM for P, ARCH D, STR D, and BS D:

BIM A 2.1 BIM Collaboration:

a) Requirements and strategies are defined for supporting BIM collaboration between internal and external parties,

b) Requirements and strategies are defined for exchanging the model and the facility information between phases and processes,

c) Defined BIM collaboration strategies are implemented,

d) Defined exchange strategies of the model and the facility information are implemented.

Shared servers, which can be accessed from all of the three locations, is used for internal collaboration and facility information sharing. Additionally, they usually share files via e-mail. Shared, Work in Progress, Published, Archived folders are created in the servers for each project in accordance with PAS 1192-2007 collaboration standard. Naming conventions of the folders are also defined based on PAS 1192-2007.

For BIM collaboration and facility information sharing with external stakeholders, they use common data environments and document management tools such as M-files and ACONEX. For one of their existing projects, M-Files is a common area where the contractor, the employer, the consultant and the designer collaborate and share information.

BEP is usually created as the first step of design workflow. They use the BIM Project Execution Planning Guide of the Computer Integrated Construction (The Pennsylvania State University, 2011) as the BEP template. BEP is created based on the technical specifications of the customer and the BIM processes. After development of BEP, it is shared with the client for approval. BEP is updated based on the client's suggestions. They also define how to conduct coordination meetings in BEP. Meetings are held more often during the detail design stage. They define BIM collaboration and information sharing procedures within the company. For example, they created a guideline to describe how to use M-files for information sharing.

BIM A 2.2 Interoperability:

a) Interoperable formats are made available and used to support data exchange between BIM software and other construction software applications.

In Navisworks, clash detection is exported in different interoperable formats such as .html, .xml and clash test viewpoints. These formats are imported into Navisworks by different stakeholders to check the conflicts again. Additionally, IFC is used to exchange models with their external stakeholders. In conceptual planning, they create models from point cloud data which is collected with laser scanners.

Level 3 – Optimized BIM for P, ARCH D, STR D, and BS D:

BIM A 3.1 Corporate-wide BIM Deployment:

a) Model is used for all processes and embraced by all team members,

b) Required facility information for different processes are extracted from the model and provided for the use of all team members,

c) Change management and synchronization of the model are established and the model updates are tracked, and

d) BIM objects and facility information are collected in a library for reusing this information on future projects.

Tenders are prepared from models. Construction progress is also tracked from models. However, models cannot be visualized from site at the moment. They are creating a sub-structure to be able to view models through tablets by using Autodesk 360. Thus, we concluded that the model is not transferred to other processes/phases and is not embraced by all stakeholders.

They have two types of change requests. The first type of change requests come from their clients during the approval process of a project. The first type of change requests comes with official writings. Professionals from each discipline take their own notes on the model during coordination meetings with the contractor and revises the model according to these notes. Both the models and the notes include details of change requests and these are archived. Changes made on the model are stored in relation to the notes so that they can track which version of model is released after each change request. Then, the latest version of the model is published by using M-files for sharing it with all stakeholders. The second type of change requests comes from construction site. These type of change requests come in excel format via e-mail. As a result of implementing these change requests into the models, As-Built models are created.

Frequently used BIM objects are identified and collected in a folder which is located in their shared server. Also, if they work with other design offices they share these objects with them to make these offices create designs that are compatible to their system. They also use default objects in Revit.

BIM A 3.2 Continuous BIM Improvement:

a) A feedback mechanism is created to identify common causes of variations in BIM usage,

b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified, and

c) An implementation strategy is established to achieve BIM improvement objectives.

They follow international construction reports for the latest BIM technology. They also attend related conferences, and join competitions if their clients allow them to do. When a problem arises, they tend to find a quick solution. They usually ask to the BIM expert for a solution. There is not a systematic approach for investigating BIM related problems and solving them.

4.4 Implementation of the Multiple Case Studies

We applied the model in four different organizations. We describe the selection reason of each company and explain the findings of each case study under each case study title.

For each case study, we asked pre-defined interview questions and filled the excel based assessment template to assess selected processes/phases. Excel sheet of each company, which includes ratings of the BIM outcomes and BIM attribute outcomes, can be found in Appendix F. Secondly, assessment indicators such as models created by using Revit, which are listed in the checklist, are observed and notes are taken during the interviews. Additionally, each assessment indicator in the checklist is marked according to its existence. Marked checklists of the companies is given in Appendix H. Voice recording of the whole interview is collected. Findings are discussed for clarification and the online questionnaire is applied to the interviewees for validating the findings and the ratings of the assessment. Questionnaire answers of the interviewees in each company are given in Section 4.5. Assessment reports of each case study are written based on the voice recording, the excel-based notes and ratings, the notes about assessment indicators, and the checklist.

We used the four-point ordinal scale which is explained in Section 3.1.2. Not Achieved (N – 0 point), Partially Achieved (P – 1 point), Largely Achieved (L – 2 points), Fully Achieved (F – 3 points) and Not Available (N/A) are represented as “Red”, “Yellow”, “Blue”, “Green” and “Grey”, respectively. To achieve a BIM capability level, all BIM attributes of that level should be rated as L or F.

4.4.1 *Case study 1 in Company B for Structural Design*

4.4.1.1 *Demographic Information*

Company B was founded in 1989 and is located in Ankara. It has less than 50 employees including civil engineers, and technicians. The company works on structural design and detailing of steel and reinforced concrete projects. They have been working on this area for 28 years. They are working on structural design of various facility types which are buildings, airports, sports facilities and industrial plants. They have more experience in designing steel frames. Some of their employees have professional engineering certificates.

We selected Company B since they work on designing both steel and reinforced concrete frames. We wanted to observe the applicability of BIM-CAREM in two different frame types.

4.4.1.2 *Findings of the Assessment*

Since the company specializes in structural design, the assessment is conducted for the processes which are as follows:

- STR D3 – Make Global Design
- STR D4 – Make Detail Design, and
- STR D5 – Do Design Tasks During Construction.

These processes are assessed for both steel and reinforced concrete projects. Two hours meeting is conducted with three civil engineers, and two technicians. One of the civil engineers is working as the project manager, one of them is specialized in structural analysis, and the other civil engineer is working as the designer. Ratings of the BIM outcomes/BIM attribute outcomes are collected in the excel sheet of Company B which can be found in Appendix F. Marked checklist for Company B is given in Appendix H. Questionnaire results are given in Section 4.5. Assessment report of Company B are given below.

BIM capability level of structural design of steel frames and structural design of reinforced concrete frames are determined based on the ratings of BIM attributes presented in Table 24. There is a small difference between the practices of structural design of steel frames and structural design of concrete frames. While they can facilitate digital fabrication from models for steel frames, digital fabrication of concrete frames cannot be performed. Therefore, there is an enterprise level of BIM usage in structural design of steel frames, but they cannot use BIM at the enterprise level for structural design of concrete frames. In spite of this difference, both of the structural design of steel frames and structural design of reinforced concrete frames are found at BIM Capability Level 2-Integrated BIM as presented in Figure 15. This capability level is determined because, they do not have any strategy for identifying BIM related problems and improving BIM usage in the company, continuously. Therefore, Continuous BIM Improvement BIM attribute is rated as “Partially Achieved” in Table 24.

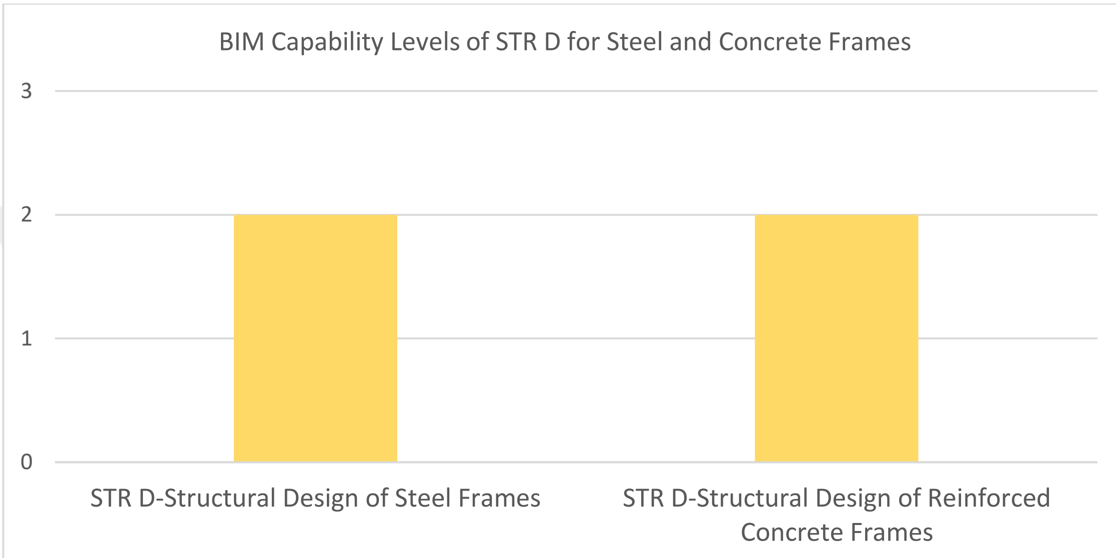

Figure 15 Achieved BIM capability levels of structural design of steel and concrete structures for Company B

Final ratings of each BIM attribute with respect to structural design of steel and concrete frames are presented as ordinal values (F, L, P, N) in Table 24. These ratings are derived from ratings of BIM outcomes/BIM attribute outcomes which are presented in Figure 16. Ratings of BIM outcomes/BIM attribute outcomes are aggregated for calculating the score of the associated BIM attribute.

Table 22 BIM attribute ratings for Company B's structural design of steel and reinforced concrete frames

Phase / BIM Attribute	Level 1-Performed BIM		Level 2-Integrated BIM		Level 3-Optimized BIM	
	BIM A1.1	BIM A1.2	BIM A2.1	BIM A2.2	BIM A3.1	BIM A3.2
STR D-Structural Design of Steel Frames	F	F	L	F	L	P
STR D-Structural Design of Reinforced Concrete Frames	F	F	L	F	P	P

Based on the case narrative of Company B, which is explained below, a rating is given for each BIM outcome of the processes STR D3, STR D4 and STR D5. Moreover, a rating for each BIM attribute outcome of the BIM Attributes are given based on the assessment findings. Ratings of BIM outcomes and BIM attribute outcomes are summarized in Figure 16 by using the color coding. Detailed ratings can be found in Appendix F. In Figure 16, interval values 3, 2, 1, and 0 are represented by "Green", "Blue", "Yellow" and "Red", respectively. Not Available (N/A) value is represented as the color "Grey". In order to find the composite rating value of each BIM Attribute, median value of the single BIM outcomes/BIM attribute outcomes ratings are taken by using the rules explained in Section 3.1.2. These median values of BIM outcomes/BIM attribute outcomes ratings are equal to the composite values of BIM attributes which are given in Table 24.

STR D-Structural Design for Steel Frames		
BIM A1.1	**BIM A2.1**	**BIM A3.1**
STR D3-1	BIM A2.1-a	BIM A3.1-a
STR D3-2		
STR D3-3	BIM A2.1-b	BIM A3.1-b
STR D3-4		
STR D4-1	BIM A2.1-c	BIM A3.1-c
STR D4-2		
STR D4-3	BIM A2.1-d	BIM A3.1-d
STR D4-4		
STR D5-1		
BIM A1.2	**BIM A2.2**	**BIM A3.2**
BIM A1.2-a	BIM A2.2-a	BIM A3.2-a
BIM A1.2-b		BIM A3.2-b
BIM A1.2-c		BIMA3.2-c

STR D-Structural Design for Reinforced Concrete Frames		
BIM A1.1	**BIM A2.1**	**BIM A3.1**
STR D3-1	BIM A2.1-a	BIM A3.1-a
STR D3-2		
STR D3-3	BIM A2.1-b	BIM A3.1-b
STR D3-4		
STR D4-1	BIM A2.1-c	BIM A3.1-c
STR D4-2		
STR D4-3	BIM A2.1-d	BIM A3.1-d
STR D4-4		
STR D5-1		
BIM A1.2	**BIM A2.2**	**BIM A3.2**
BIM A1.2-a	BIM A2.2-a	BIM A3.2-a
BIM A1.2-b		BIM A3.2-b
BIM A1.2-c		BIMA3.2-c

Figure 16 Ratings of BIM outcomes and BIM attribute outcomes

Ratings of each BIM outcome and BIM attribute outcomes are determined based on the case narratives of Company B. They include the assessment findings and collected evidences for BIM outcomes and BIM attribute outcomes which are summarized below.

<u>Level 1 – Performed BIM for STR D of Steel and Reinforced Concrete:</u>

<u>BIM A 1.1 Performing BIM:</u>

<u>STR D3-1, STR D3-4, STR D4-1 Design authoring:</u> In order to create structural models, they need architectural model. However, architectural design is mostly sent them late. Therefore, this usually create time constraints for the company. Structural design of steel frames is created by using Tekla Structures and structural design of reinforced concrete frames are prepared by using Allplan. Additionally, they are using Rhino with Grasshopper. All employees are working on the workstations. They have licenses of all design authoring tools. Examples of steel and reinforced concrete frame models are observed and it is seen that models have parametric intelligence.

STR D4-2 Engineering analysis: They are using Sap 2000 and ETABS for structural analysis of steel projects and for structural analysis of reinforced concrete projects, respectively. Additionally, they are using Safe and Scia for structural analysis. In order to conduct analysis, a new model is developed, since importing the existing model into structural analysis tools does not create efficient result. The LOD of the models, which are used for structural analysis, is usually LOD 100/LOD 200 since they do not need most of the details which are included in the main model.

STR D3-2, STR D3-1 3D coordination: Clash detection for steel and reinforced concrete frames are conducted with Tekla Structures and Allplan, respectively. Two example of clash detection reports from Tekla and Allplan are analyzed. 3D coordination of steel and reinforced concrete projects differ from each other. Conflicts with building services design usually occur more in reinforced concrete frames. They usually have less clashes between structural design of steel frames and building services design. In one of their projects there was a BIM team which is only responsible for coordination. Models from all the disciplines, such as architectural and structural design, are coordinated regularly by the BIM team. They were sending their models in a period of time for 3D coordination. Additionally, very small pieces of models were coordinated instead of coordinating the complete models. In some cases, clash detections are recognized during the fabrication. Manufacturers inform them for elimination of these clashes. They update the model and send it back to the manufacturers.

STR D4-3 Cost estimating: A quantity takeoff example from a steel frame design is observed and they are using BIM for estimating costs.

STR D4-4 Phase and 4D planning: Since they work with general contractors, they do not create work schedules. Thus, they do not use BIM for phase and 4D planning.

STR D5-1 Record modelling*:* They do not conduct As-Built modelling since As-Built models are not requested by most of their contractors. Moreover, change requests usually come very late from the site.

BIM A 1.2 BIM Skills:

a) Staff with BIM trainings and/or BIM experience are employed,

b) Employees are supported in taking BIM trainings, and

c) BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged.

All of employees, who are using Tekla, were sent to BIM training. Peer-learning is encouraged within the company, and new employees learn from the ones who have BIM certificates. They also conduct BIM trainings within the company. However, external trainings are given only when new technology is introduced. For example, when they started to use Allplan, a trainer came to the company and gave Allplan training to all of the company employees.

There is a work flow in the company, they explain this work flow to new employees. Moreover, when a new employee is stuck in a point, the process is stopped and work flow is explained again. When a new feature is discovered related to BIM, it is explained to all employees in a meeting.

According to them, BIM skills and experience of an employee is important depending on the role. They have customized settings in Tekla and Allplan. For this reason, they prefer to hire staff with beginner level of BIM skills and experience. They prefer to encourage peer-learning. They regularly attend the NASCC which is an important conference related to steel frames.

Level 2 – Integrated BIM for STR D of Steel and Reinforced Concrete:

BIM A 2.1 BIM Collaboration:

a) Requirements and strategies are defined for supporting BIM collaboration between internal and external parties,

b) Requirements and strategies are defined for exchanging the model and the facility information between phases and processes,

c) Defined BIM collaboration strategies are implemented,

d) Defined exchange strategies of the model and the facility information are implemented.

They have their own collaboration standards within the company but they do not have standards for collaborating with external stakeholders. They usually adapt their project deliveries to the contractors' standards. They have a shared server in the company. They have the same folders for each of their projects and they are using naming conventions for files and folders. They do not use a document system within the company. However, if contractor has a standard system for collaboration and information exchange, they use the contractor's system. For example, they used ACONEX in some of their projects. Otherwise, they send the models via e-mails.

They share models with each other in the company at regular points in time. They check models for eliminating clashes. The models are shared when the models are at LOD 200-250 detail level.

BEP is not created for all of their projects. In one of their projects, there was a BIM team which is only responsible for coordination. Models from all the disciplines were coordinated by this intermediary team. In one of their projects, they submitted the models in every two days for coordination. The models of this project were prepared based on some principles for effective coordination. They also attended coordination meetings. Responsible parties for solving the clashes/conflicts were identified at the beginning of the project. According to them, choosing the products which can be found in the market eliminates many conflicts. In one of their projects they were both designer and detailer which allowed them to create design efficiently.

BIM A 2.2 Interoperability:

a) Interoperable formats are made available and used to support data exchange between BIM software and other construction software applications.

They follow the technology and get the latest versions of their software, because models created in the next versions cannot be opened in the previous versions. They use IFC, if a project contains both concrete and steel frames.

Level 3 – Optimized BIM for STR D of Steel and Reinforced Concrete:

BIM A 3.1 Corporate-wide BIM Deployment:

a) Model is used for all processes and embraced by all team members,

b) Required facility information for different processes are extracted from the model and provided for the use of all team members,

c) Change management and synchronization of the model are established and the model updates are tracked, and

d) BIM objects and facility information are collected in a library for reusing this information on future projects.

They are conducting digital fabrication for steel frames. In one of their projects, models, which were crated in Tekla, are sent in "NC" format to their manufacturer for digital fabrication. The CNC produces steel frames from the model. If models are designed properly in Tekla, for example if all cutting points are marked, the producer can make the production without any problems. Tekla structures are used widely in factories in Turkey. However, they are not conducting digital fabrication from models for reinforced concrete frames. Most of their contractors do not request using models in FM. Thus they do not add additional information into model since it brings an extra cost for them.

After detailed design, they add many types of information into the model which makes filtering difficult. But if one of their clients requests, they can assign a property in Tekla and put the related elements under this property.

They use a project management system throughout the company. They enter their efforts on daily basis. Revisions usually come via e-mail. When a client requests a revision, they create a revision work order, which has an ID, in the project management system. They later filter out how much time is spent on this revision. And they collect information about how much material is affected because of this revision.

They have a library of BIM objects which they use frequently. In addition, they created custom details for models in Tekla. Some of these details are fixed and they appear in all models. Since Tekla is a multi-user program, all users are notified when a model is updated.

BIM A 3.2 Continuous BIM Improvement:

a) A feedback mechanism is created to identify common causes of variations in BIM usage,

b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified, and

c) An implementation strategy is established to achieve BIM improvement objectives.

They experienced difficulties in modelling spiral staircases geometrically. They conducted research for finding solutions for improvement. In some cases, they talked to their software vendors to solve these problems. There is not any written strategy involving BIM improvement objectives. Most of the problems are solved instantly. They are following new BIM technologies especially about steel frames. They also attend the NASCC every year which is an important conference related to steel frames.

about steel frames. They also attend the NASCC every year which is an important conference related to steel frames.

4.4.2 *Case study 2 in Company C for Architecutral Design*

4.4.2.1 *Demographic Information*

Company C is an architectural design firm located in Ankara which designs buildings such as hotels. They have been working in this area for 20 years. Company C has less than 10 employees. Although the company did not work in any project in which BIM is a contract requirement, they are using BIM in the organization for their own benefit.

We selected Company C, since it is an architectural design firm focuses on only one facility life cycle stage. It is a small firm with less than 10 employees. We wanted to observe the applicability of BIM-CAREM in a small organization which focuses on single facility life cycle stage. Additionally, Company C has never worked in a project in which BIM is a contract requirement. Thus, we wanted to see the similarities and differences between the assessment results of a company that uses BIM as contract requirement and a company that uses BIM without a contract requirement.

4.4.2.2 *Findings of the Assessment*

Architectural design processes are evaluated with the context of the appraisal. These processes are as follows:

- ARCH D3 – Make Global Design,
- ARCH D4 – Make Detail Design, and
- ARCH D5 – Do Design Tasks During Construction.

For assessing these processes, a meeting for two hours was conducted with the architect who is the owner of the company. Ratings of BIM outcomes/BIM attribute outcomes are collected in the excel sheet of Company C which can be found in Appendix F. Marked checklist for Company C is given in Appendix H. Questionnaire results are given in Section 4.5. Case narratives of Company C are given below.

BIM capability level of architectural design is determined based on the ratings of BIM attributes, which are presented in Table 25, by using the rules given in Table 18 in Section 3.1.2. Although the rating of BIM Skills is N/A in Table 25, architectural design of Company C is found at BIM Capability Level 1-Performed BIM which is presented in Figure 17. This is because, Company C has been using BIM only for its own benefit and they have not taken place in any project which has BIM as a contract requirement. Therefore, although they are implementing BIM in their practices, they do not have a possibility to collaborate with their stakeholders by using BIM.

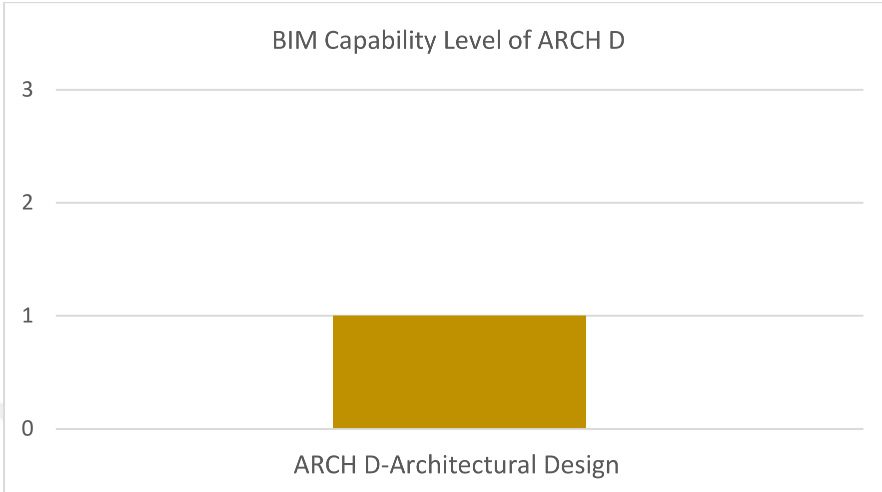

Figure 17 Achieved BIM capability level of architectural design for Company C

Final ratings of each BIM Attribute with respect to architectural design presented as ordinal values (F, L, P, N) in Table 25. These ratings are derived from the ratings of BIM outcomes and BIM attribute outcomes which are presented in Figure 18. Ratings of BIM outcomes/BIM attribute outcomes are aggregated for calculating the score of the associated BIM attributes. Due to the environment in which stakeholders have lack of BIM use, we could not gather enough evidence to give rating for BIM Skills, BIM Collaboration, Interoperability, Corporate-wide BIM Deployment and Continuous BIM Improvement. Thus, their ratings are N/A in Table 25. Detailed explanations for each BIM outcome and BIM attribute outcome are explained below.

Table 23 BIM attribute ratings for Company C's architectural design

Phase / BIM Attribute	Level 1-Performed BIM		Level 2-Integrated BIM		Level 3-Optimized BIM	
	BIM A1.1	BIM A1.2	BIM A2.1	BIM A2.2	BIM A3.1	BIM A3.2
ARCH D-Architectural Design	L	N/A	N/A	N/A	N/A	N/A

Based on the case narratives of Company C, which are explained below, a rating is given for each BIM outcome of the processes ARCH D3, ARCH D4, and ARCH D5, and a rating for each BIM attribute outcomes. Ratings of BIM outcomes and BIM attribute outcomes are summarized in Figure 18 by using the color coding. Detailed ratings can be found in Appendix F. In Figure 18, interval values 3, 2, 1, and 0 are represented by “Green”, “Blue”, “Yellow” and “Red”, respectively. Not Available (N/A) value is represented as the color “Grey”. In order to find the composite rating value of each BIM Attribute, median value of the single BIM outcomes/BIM attribute outcomes ratings are taken by using the rules explained in Section 3.1.2. These median values of BIM outcomes/BIM attribute outcomes ratings are equal to the composite values of BIM attributes which are given in Table 25.

ARCH D-Architectural Design		
BIM A1.1	**BIM A2.1**	**BIM A3.1**
ARCH D2-1	BIM A2.1-a	BIM A3.1-a
ARCH D2-2		
ARCHD3-1		
ARCHD3-2		
ARCHD3-3	BIM A2.1-b	BIM A3.1-b
ARCHD3-4		
ARCHD3-5		
ARCHD3-6		
ARCHD3-7		
ARCHD4-1	BIM A2.1-c	BIM A3.1-c
ARCHD4-2		
ARCHD4-3		
ARCHD4-4		
ARCHD4-5		
ARCHD4-6	BIM A2.1-d	BIM A3.1-d
ARCHD4-7		
ARCHD4-8		
ARCHD4-9		
ARCHD5-1		
BIM A1.2	**BIM A2.2**	**BIM A3.2**
BIM A1.2-a	BIM A2.2-a	BIM A3.2-a
BIM A1.2-b		BIM A3.2-b
BIM A1.2-c		BIM A3.2-c

Figure 18 Ratings of BIM outcomes and BIM attribute outcomes

Ratings of each BIM outcome and BIM attribute outcomes are determined based on the assessment report of Company C. It includes the assessment findings and collected evidences for BIM outcomes and BIM attribute outcomes which are summarized below.

Level 1 – Performed BIM for ARCH D:

BIM A 1.1 Performing BIM:

ARCH D2-1 Draw up space program and requirements are developed (areas, volumes and etc.): After they receive customer's requirements, they study on these requirements for interpreting them. They conduct meetings with their clients for clarifying these requirements. These tasks do not include BIM.

ARCH D2-2 Programming: They do not use BIM for assessing design performance.

ARCH D3-1, ARCH D3-2, ARCH D3-3, ARCH D3-6, ARCH D4-2, ARCH D4 -2 Design authoring: They use Autodesk Revit for creating architectural models. They are producing standalone models, and they do not collaborate with their stakeholders by using these models. Their design work flow starts with creating conceptual design. Conceptual design includes layout design which is a scaled diagram of a building viewed from above and includes measurements. Hand drawing is used until the logic of the plan/design is prepared. Secondly, they create preliminary design based on client's requirements. BIM is involved in the preliminary design. Design is transferred into 3D model by using Revit. They share the preliminary design with their customers in order to get approval. However, they do not use BIM for sharing and collaborating with their customers. Detailed design is created after the sub-contractors such as for roofing, HVAC, windows and doors are selected. Finally, they create construction documents which is the final design and very similar to real building.

BIM was not a contract requirement in their projects. They are using BIM for their own benefit. In only one project, they are involved in a fully coordinated project. In that project, they created 3D models by using Revit and Rhyno. Elements of this building, which are reinforced concrete, are produced by using the model in a factory in Turkey. Later, these elements are assembled on the site.

ARCH D3-4 ARCH D4-3 3D coordination: According to them, until information comes from other design disciplines, 3D coordination is not very crucial. 3D coordination is conducted when structural and building services designs are received.

ARCH D3-5 Code and compliance checking is performed: They perform rule checking manually.

ARCH D3-7 An application for a building permit is submitted: Municipalities mostly do not require any 3D models. Therefore, they do not include models, which are created by using BIM tools, in the application package.

ARCH D4-1 Design review: They are reviewing preliminary design by using BIM.

ARCH D4-5 Cost estimating: They are not creating quantity take off from the model. They usually estimate the cost of a new building project by using the cost calculator of Chamber of Architects of Turkey (Turkish Chamber of Architects, n.d.).

ARCH D4-6 Phase and 4D planning: They are not preparing phase and 4D planning, since most of their customers do not request this information. Mostly general contractors create phase planning.

ARCH D4-7 Engineering analysis and ARCH D4-8 Sustainability analysis: The company do not conduct any engineering or sustainability analysis such as LEED analysis.

ARCH D4-9 Tender documents including BIM protocols are created: Since they are working as a sub-contractor for general contractors, they are not creating tender documents.

ARCH D5 – 1: Record modeling: They usually continue designing until the building is opened. They, also create the As-Built models.

BIM A 1.2 BIM Skills:

a) Staff with BIM trainings and/or BIM experience are employed,

b) Employees are supported in taking BIM trainings, and

c) BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged.

Although they have not attended to any BIM trainings, they facilitated self-learning for using BIM and Revit more effectively. However, they did not need to hire any BIM skilled professionals since they did not take any BIM mandatory project. Therefore, we could not collect enough evidence to give a rating for this BIM attribute.

Level 2 – Integrated BIM for ARCH D:

There is a shared server for storing architectural design within the company. Files and folders in this server have a standard structure and naming convention. However, these procedures and standard naming conventions are not related to BIM. Since they do not work in the projects with BIM contract requirements, they cannot make any collaboration with their stakeholders by using BIM. Therefore, we could not collect enough evidences to measure the BIM A 2.1 BIM Collaboration and BIM A2.2 Interoperability of BIM Capability Level 2 – Integrated BIM.

Level 3 – Optimized BIM for ARCH D:

Similarly, since they do not have any BIM practice for using BIM in the enterprise level, we could not collect enough evidence to measure the BIM A3.1 Corporate-wide BIM Deployment and BIM A3.2 Continuous BIM Improvement attributes.

4.4.3 *Case study 3 in Company D for Construction*

4.4.3.1 *Demographic Information*

Company D is established in 1993 and is a general contractor and investor in 24 countries throughout the world. According to the 2016 ENR Top 250 International Constructors list (ENR, 2016), Company D is within the top 50 of international constructors in the world. The company specializes in design and construction of various types of facilities such as buildings, industrial facilities, multifunctional complexes and shopping malls. They are operating in Russia and Turkey, as well as in the regions such as Europe and Middle East. The company follows and actively uses new technologies in AEC/FM industry such as BIM, lean construction, sustainability and green building.

We conducted the case study with one of their group company which is the Healthcare Investment Group. Healthcare group, which is located in Ankara, was established in 2012. The group has expertise in working on building hospitals and healthcare complexes for about 5 years. They have healthcare projects such as Integrated Health Campuses at different cities in Turkey. There are more than 200 white collar employees in Healthcare Investment Group and 6 employees in BIM team.

We selected Company D, since it is an international constructor working in different regions of the world and using BIM effectively. Also they are constructing medical facilities differently than the other companies involved in the multiple case studies. We wanted to observe the applicability of BIM-CAREM for identifying BIM capability of construction process in hospital projects. We also wanted to see if BIM-CAREM is applicable to different sizes of organizations.

4.4.3.2 *Findings of the Assessment*

Since Company D is an international constructor, we focused on assessing construction phase. The assessment is conducted for the processes which are as follows:

- C1 – Acquire Construction Services
- C2 – Plan and Control the Work,
- C3 – Provide Resources, and
- C4 – Build Facility.

Two hours meeting was conducted with the architect and the BIM supervisor of the company. Ratings of the BIM Outcomes/BIM Attribute Outcomes are stored in the excel sheet of Company D which can be found in Appendix F. Marked checklist for Company D is given in Appendix H. Questionnaire results are given in Section 4.5. Assessment report of Company D, which includes the assessment findings, is given below.

BIM Capability Level of Construction is determined based on the ratings of BIM Attributes, which are presented in Table 26. The company implements BIM in most of their practices by achieving the BIM outcomes and they have the required BIM skilled employees. They use BIM to integrate different processes/phases by facilitating BIM collaboration and are using interoperable formats. They also use BIM at the enterprise level. Based on the findings, which are explained below, construction stage of Company D is found at BIM Capability Level 3-Optimized BIM which is presented in Figure 19.

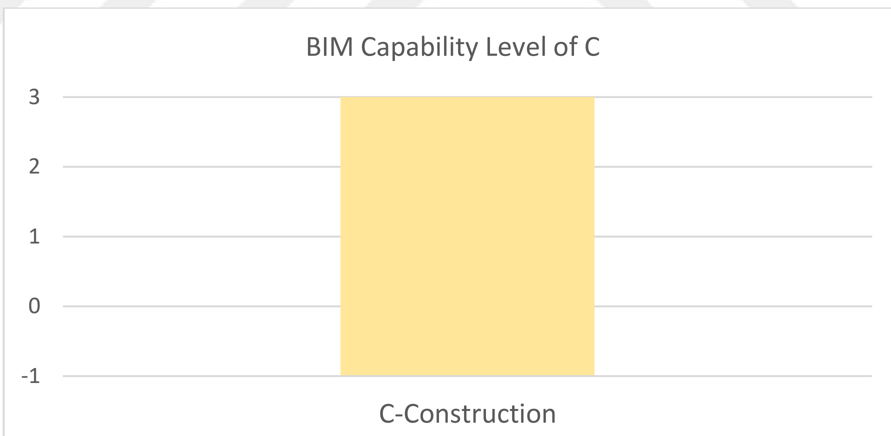

Figure 19 Achieved BIM capability level of construction for Company D

Final ratings of each BIM Attribute with respect to Construction presented as ordinal values (F, L, P, N) in Table 26. These ratings are derived from ratings of BIM outcomes and BIM attribute outcomes which are presented in Figure 20. Ratings of BIM outcomes/BIM attribute outcomes are aggregated for determining the score of the associated BIM attributes. According to the findings, they are implementing BIM fully in their practices. They pay attention to BIM experience and BIM skills of their employees. Therefore, we gave the rating of "Fully Achieved" to the attributes of both Performing BIM and BIM Skills. They also collaborate with their stakeholders by using BIM. They receive models from their design offices in IFC format. Thus, BIM Collaboration and Interoperability is rated as "Fully Achieved". Moreover, they use BIM at the enterprise level. For example, they handle progress payments through BIM. Therefore, they got "Fully Achieved" rate for Corporate-wide BIM Deployment. They conduct innovation meetings weekly for tracking new technologies in the AEC/FM industry. On the other hand, they do not have written strategies for identifying BIM related problems and solving those problems. Thus, they are rated as "Largely Achieved" for Continuous BIM Improvement.

Table 24 BIM attribute ratings for Company D's construction

Phase / BIM Attribute	Level 1-Performed BIM		Level 2-Integrated BIM		Level 3-Optimized BIM	
	BIM A1.1	BIM A1.2	BIM A2.1	BIM A2.2	BIM A3.1	BIM A3.2
C-Construction	F	F	F	F	F	L

Based on the assessment findings of Company D, which is explained below, a rating is given for each BIM outcome of the processes C1, C2, C3, and C4 and a rating for each BIM attribute outcome of the BIM attributes. Ratings of BIM outcomes and BIM attribute outcomes are summarized in Figure 20 by using the color coding. Detailed ratings can be found in Appendix F. In Figure 20, interval values 3, 2, 1, and 0 are represented by "Green", "Blue", "Yellow" and "Red", respectively. Not Available (N/A) value is represented as the color "Grey". In order to find the composite rating value of each BIM Attribute, median value of the single BIM outcomes/BIM attribute outcomes ratings are taken by using the rules explained in Section 3.1.2. These median values of BIM outcomes/BIM attribute outcomes ratings are equal to the composite values of BIM attributes which are given in Table 26. Detailed explanations are given below for each BIM outcome and BIM attribute outcome.

C-Construction		
BIM A1.1	**BIM A2.1**	**BIM A3.1**
C1-1	BIM A2.1-a	BIM A3.1-a
C1-2		
C1-3		
C1-4		
C2-1	BIM A2.1-b	BIM A3.1-b
C2-2		
C2-3		
C2-4		
C2-5	BIM A2.1-c	BIM A3.1-c
C3-1		
C3-2		
C3-3		
C4-1	BIM A2.1-d	BIM A3.1-d
C4-2		
C4-3		
C4-4		
C4-5		
BIM A1.2	**BIM A2.2**	**BIM A3.2**
BIM A1.2-a	BIM A2.2-a	BIM A3.2-a
BIM A1.2-b		BIM A3.2-b
BIM A1.2-c		BIMA3.2-c

Figure 20 Ratings of BIM outcomes and BIM attribute outcomes

Ratings of each BIM outcome and BIM attributes outcomes are determined based on the assessment report of Company D. It includes the assessment findings and collected evidences for BIM outcomes and BIM attribute outcomes which are summarized below.

Although we did not assess the design processes, interview is started with the details of the design phase. BIM design team was established in the Healthcare Investment group of the company, first. Now, they transfer accumulated BIM knowledge to the other groups of Company D. Since they have large scale projects, they cannot make design in house. They work with design offices and this leads to some problems in BIM implementation. They also have time constraints in most of their projects. Therefore, they have to work with more than one architectural offices simultaneously so that they can complete the projects on time. Their designers send parts of the models in IFC format. They do not wait to start construction for models to be ready with all details.

Architectural design starts with AutoCAD drawings which come from their designers. Architectural design is composed of four steps which are 1-Concept Design, 2-Detail Design, 3-Construction Documents, and 4-Shop Drawing. Among these phases, BIM is involved in the detail design. Their main focus is getting the quantity take-off from the model. Therefore, they start to use BIM when budget is started to be estimated. In the detail design phase, CAD drawings, which are suitable for budget planning, are handed in and models are created based on these CAD files.

First of all, structural model is created. All of the information, which is coming from the structural designer, is registered to the first version of the model. Details such as walls do not exist here, since static calculations are important at this stage. Then, quantity is taken from first structural model for supporting pre-budget. This value represents the approximate cost of the building in terms of reinforced concrete.

Architectural detail design starts with modeling walls. Since they have large scale projects such as 450 thousand m^2 of hospital projects, it is not easy to make revisions on the models. In small or medium size projects, designers can model the whole building at the detail design. However, such large-scale projects require staged modeling since they do not want to go back and revise the model to increase the detail level.

In their description, if a model includes information about the sub-contractors that will construct those elements, this model is at LOD 400. In other words, the amount of information added to the elements is important, but not the geometric details of the elements. Their models have layers in which information is collected. In that way, all the data is included in the models and a model has a structure which is suitable for making various types of analysis. They integrate models coming from all disciplines in Navisworks and conduct clash detection. They do not conduct energy analysis and structural analysis based on BIM. On the other hand, they have LEED golden certificate for one of their office buildings.

Level 1 – Performed BIM for C:

BIM A 1.1 Performing BIM:

C1-1 Qualified parties with BIM capability who will be invited to bid on a work package are identified and C1-3 Proposals are reviewed and BIM using constructor/subcontractors are selected based on the criteria set by the staffing plan: In order to start using BIM from design phase, they need to seek whether the potential qualified parties use BIM, or not. However, it is difficult to find architectural design firms who use BIM in Turkey. Although the situation in structural design is mostly similar to the situation in architectural design, they can find building services design offices that use BIM, since there is a big shift towards adopting BIM among building services design offices. As these offices use Revit for creating models, Company D continue to use Revit for the following tasks in building services design.

C1-2 Proposals for bid including BIM costs are prepared by qualified parties: Building services designers include BIM clauses in their bid proposals. However, since they claim to not being able to find architectural and structural design offices that use BIM in Turkey, BIM is not included in these designers' bid proposals.

C1-4 Contracts including BIM clauses are formalized: They include BIM clause in their contracts if design offices/sub-contractors use BIM for performing their tasks.

C2-1 Phase and 4D planning: Construction sequencing is created: They usually create 4D and phase planning before construction starts. The planning office creates work schedules in Primavera. Just after completing reinforced concrete models, work schedules are integrated with models in Navisworks. Sometimes mistakes may occur in work schedules and these mistakes can be recognized via these simulations and then corrected. Therefore, this procedure plays an important role for enabling collaboration among the departments. 4D and phase planning is not created for building services design.

C2-2 Site utilization planning: BIM is used to graphically represent facilities on site which can include labor resources, materials with associated deliveries, and equipment location: Site utilization planning isn't conducted by using BIM. However, workforce is planned by using BIM. Models contain information about responsible sub-contractor of each facility element. It also includes information about construction date of each facility elements.

C2-3 5D cost estimating is used for developing the budget: They do not create quantity take-offs manually. They rely on the quantities which are obtained from the models. After the reinforced concrete model is completed, quantity take off is shared with the site, central, and technical offices. They store these take-offs in Excel sheets and share them in ".xls" format. Later, they take quantities for detailing work and share them with both the site and design offices. However, in the meantime, change requests can come for reinforced concrete design. While some designers model the detailed work, some of them update the models in terms of change requests. Later they merge the models. Hence, quantity take-off is created based on the merged model. They prepare cost estimations for architectural and structural designs in three months' periods. Except from this, it is also required to update the model in terms of revisions coming from the site.

C2-4 Shop drawings are created using BIM: Shop drawings are created by reflecting the change requests, which are coming both from the site and design offices. Later, shop drawings are used to create As-Built models.

C2-5 Status/progress monitoring is visualized from site data: There are installed cameras on the site and they gather 360-degree view from the site. Model and site pictures are united and construction progress is monitored via BIM. They can follow the work flow with respect to time.

There is a 350 thousand m^2 hospital project in one of the big cities in Turkey. They have selected this project as a pilot study. Employees both in technical office and on site are using Allplan. For this project Company D created models from CAD files and sent them to the technical office. Technical office sent the models to the site. Architects and engineers on site updated the models based on the change requests and shop drawings are created immediately on site. Revisions in models, which are made on site, are marked with different color. Therefore, one can understand who has made the revision in the model. Technical office makes progress payments from the model. Without such a system it is impossible to catch the site and make the progress payments according to the model.

<u>C3-1 Resources are acquired and inventory is managed in accordance with inventory information gathered from integrated ERP and BIM tools:</u> BIM tools and ERP tools are not integrated.

<u>C3-2 Digital fabrication: Digital fabrication is facilitated:</u> As a digital fabrication example, they produced a sample from the model by using 3D printer within the company. They sent this sample to the producer to be used for manufacturing. However, there is not any direct digital fabrication from model.

<u>C3-3 The distribution priorities are determined based on 4D plan:</u> They do not plan logistics via BIM.

<u>C4-1 Daily work is executed based on 4D plan:</u> It can be seen from the model that who is going to build each element such as each wall. Additionally, an ID number is attached to every wall. AutoCAD outputs are given to sub-contractors by saying that the walls in specific locations are their responsibility. Sub-contractors then give weekly progress reports to the Company D by indicating their weekly progress such as 30% of the work is completed. These progress payments are compared with the cost estimation that has been made before.

<u>C4-2 3D location identification: Physical locations of elements on site are pinpointed for construction layout:</u> BIM is not used for pinpointing the physical locations of the elements for construction layout.

<u>C4-3 Facility is constructed by using BIM:</u> Simulations, which are created based on 4D planning, are delivered to site workers so that they can view models from their hand held devices such as tablets. They bought tablets appropriate for site use. By using BIMplus, they are able to see the model interactively. They can also make comments on models by using the tablets and these comments show up as a pop up in Allplan. It also has an appropriate structure for filtering views such as metal roof. They do not want their workers to walk around with paper drawings on hand. They utilize an online program and field engineers also use it. Currently they do not use Virtual Reality (VR) for construction but they are conducting research about using it.

<u>C4-4 Quality assurance is conducted:</u> They are not using BIM for quality assurance, but they would like to use.

<u>C4-5 Operation data is handed over to the owner with BIM:</u> BIM is handed over to their customers if it is requested.

<u>**BIM A 1.2 BIM Skills:**</u>

a) <u>Staff with BIM trainings and/or BIM experience are employed,</u>

b) Employees are supported in taking BIM trainings, and

c) BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged.

They look for employees that know modeling by using BIM and prefer to hire the ones with knowledge about BIM processes and previous experience in BIM design authoring tools. Additionally, they usually prefer experienced employees. Most of their employees have BIM skills and have worked in BIM based projects.

They give internal BIM trainings and seminars to their employees who work as engineer, architect and technician within the Company D. Except from the company-wide trainings, they also give trainings to employees who are working in their technical offices. Since they have hospital projects in twelve different cities in Turkey, they have to collaborate with a local design or construction firm for running the projects smoothly. Therefore, they give BIM trainings to their local designers for twelve weeks just before the project starts. Their BIM skilled employees give those trainings. They do not get any consultancy about BIM processes. They get support from an advisor who gives Allplan trainings.

Level 2 – Integrated BIM for C:

BIM A 2.1 BIM Collaboration:

a) Requirements and strategies are defined for supporting BIM collaboration between internal and external parties,

b) Requirements and strategies are defined for exchanging the model and the facility information between phases and processes,

c) Defined BIM collaboration strategies are implemented,

d) Defined exchange strategies of the model and the facility information are implemented.

Company D created a BIM guideline to help their technical offices modeling in conformance to their standards. They share this BIM guideline with their technical offices with which they start to make projects. This guideline includes details about how a project starts. It also includes instructions for creating models that will create accurate quantity take-offs and progress monitoring. They aim to enable designers to model correctly by looking at this document, even if they are not experienced in BIM. This guideline also includes details about roles and responsibilities of a BIM team.

They have shared servers within the company. These servers can be reached from any other offices. They are using Allplan BIMPlus and Autodesk A360 actively for collaboration. Professionals of the Company D, send comments to each other through Opentext for enterprise information management which works on the cloud. However, they didn’t add the approval process into Opentext since they thought this may cause delays. Additionally, they have an archiving system.

They are conducting meetings weekly for BIM collaboration. Professionals from BIM team and their design offices are participating in these meetings. Company D usually is not involved in the design phase since they give design tasks to their design offices. However, they give design feedback to their design offices, especially in structural and architectural design. They do not have BEPs for their projects. They don't use standards such as COBie in order to support FM.

BIM A 2.2 Interoperability:

a) Interoperable formats are made available and used to support data exchange between BIM software and other construction software applications.

They are using IFC for exchanging model between BIM design authoring tools. Additionally, they are exporting and importing data between the BIM design authoring tools, other BIM tools and other construction software applications by using direct proprietary links.

Level 3 – Optimized BIM for C:

BIM A 3.1 Corporate-wide BIM Deployment:

a) Model is used for all processes and embraced by all team members,

b) Required facility information for different processes are extracted from the model and provided for the use of all team members,

c) Change management and synchronization of the model are established and the model updates are tracked, and

d) BIM objects and facility information are collected in a library for reusing this information on future projects.

In construction, construction progress can be traced from the models. Progress payments are also linked with the model so the progress information from sub-contractors is communicated through BIM. However, BIM is not used in all of the construction processes. That's why we gave "Largely Achieved" for the first BIM attribute outcome.

Building information can be filtered and are made available to different users. Comments in BIMPlus can be seen by all users which enables updating the model instantly.

They have change management procedures for the models and an archiving system for storing different versions of the models.

They have 3D object libraries which is a collection of elements such as walls, doors and windows. This library is different than the built-in libraries of Revit and Allplan programs. Additionally, they have benchmarks for project management. They give tenders according to historical data which was accumulated from previous projects.

They do not use augmented or mixed reality yet. However, they work on using these technologies in construction.

BIM A 3.2 Continuous BIM Improvement:

a) A feedback mechanism is created to identify common causes of variations in BIM usage,

b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified, and

c) An implementation strategy is established to achieve BIM improvement objectives.

They are conducting innovation meetings, weekly. They have planned goals related to BIM. For example, LEED and VR are the two goals which are at the top of their list. They are archiving educational documents and videos in the shared server.

4.4.4 *Case study 4 in Company E for Design, Construction, and Facility Management*

4.4.4.1 *Demographic Information*

Since Company E specializes in designing, constructing, and operating airports, we focused on Architectural, Structural, Building Services Designs, as well as Construction and Facility Management. Processes included in the assessment are as follows:

- ARCH D2 – Draw Up Program,
- ARCH D3, STR D3, BS D3 – Make Global Design,
- ARCH D4, STR D4, BS D4 – Make Detail Design,
- ARCH D5, STR D5, BS D5 – Do Design Tasks During Construction,
- C1 – Acquire Construction Services,
- C2 – Plan and Control the Work,
- C3 – Provide resources,
- C4 – Build Facility,
- FM1 – Plan/Control Facility
- FM2 – Manage Operations,
- FM3 – Monitor Facility Conditions and Systems,
- FM4 – Evaluate Conditions and Detect Problems,
- FM5 – Develop Solutions, and
- FM7 – Implement Plan.

Two sessions are conducted with the director of engineering and design team and BIM chief of the Company E. Each session took three hours and the interview lasted six hours in total. Ratings of the BIM outcomes/BIM attribute outcomes are stored in the excel sheet of Company E which can be found in Appendix F. Marked checklist for Company E is given in Appendix H. Questionnaire results are given in Section 4.5. Assessment report of Company E, which includes assessment findings, is explained below.

BIM Capability Level of architectural, structural, building services design, construction and facility management is determined based on the ratings of BIM Attributes, which are presented in Table 27, by using the rules given in Table 18 in Section 3.1.2. According to the findings, they use BIM in most of their design and construction practices. However, they have limited usage of BIM in their facility management practices. Their employees have BIM skills. They use BIM for integrating different processes/phase by enabling BIM collaboration with their stakeholders and usage of interoperable formats. They use BIM at the enterprise level for design and construction, but they do not use BIM at the enterprise level in facility management. Architectural, structural, and building services design, and construction processes are found at BIM Capability Level 3-Optimized and facility management processes of Company E is found to be at BIM Capability Level 1- Performed BIM as presented in Figure 21.

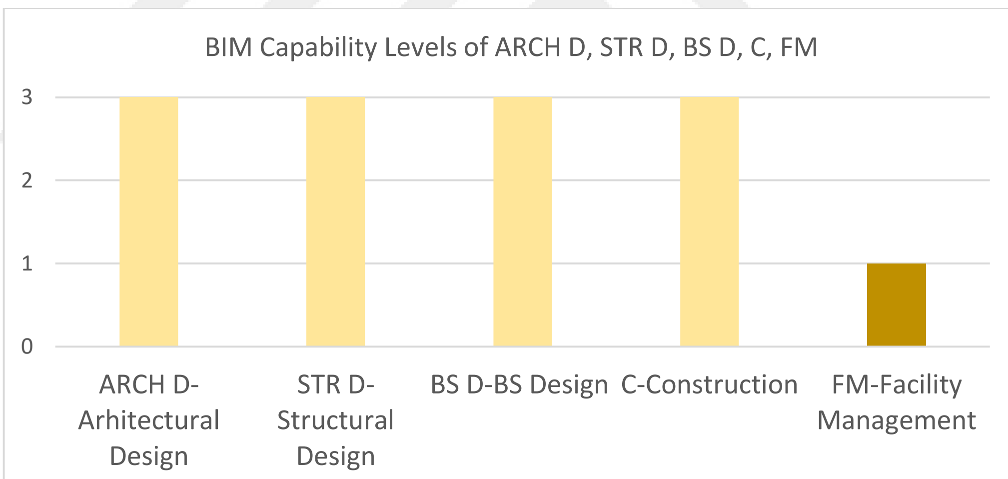

Figure 21 Achieved BIM capability levels of architectural, structural and building services design, construction and facility management for Company E

Final ratings of each BIM attribute with respect to architectural, structural, building services design, construction and facility management presented as ordinal values (F, L, P, N) in Table 27. These ratings are derived from ratings of BIM outcomes and BIM attributes outcomes which are presented in Figure 22. Ratings of BIM outcomes/BIM attribute outcomes are aggregated for calculating the score of the associated BIM attributes.

Table 25 BIM attribute ratings for Company E's architectural, structural and building services design, construction, and facility management

Phase / BIM Attribute	Level 1-Performed BIM		Level 2-Integrated BIM		Level 3-Optimized BIM	
	BIM A1.1	BIM A1.2	BIM A2.1	BIM A2.2	BIM A3.1	BIM A3.2
ARCH D-Architectural Design	F	F	F	F	F	L
STR D-Structural Design	F	F	F	F	F	L
BS D-BS Design	F	F	F	F	F	L
C-Construction	F	F	F	F	F	L
FM-Facility Management	L	F	F	F	L	L

Based on the assessment findings of Company E, which is explained below, a rating is given for each BIM outcome of the assessed processes and a rating for each BIM attribute outcome of the BIM attributes. Ratings of BIM outcomes and BIM attribute outcomes are summarized in Figure 22 by using the color coding. Detailed ratings can be found in Appendix F. In Figure 22, interval values 3, 2, 1, and 0 are represented by “Green”, “Blue”, “Yellow” and “Red”, respectively. Not Available (N/A) value is represented as the color “Grey”. In order to find the composite rating value of each BIM Attribute, median value of the single BIM outcomes/BIM attribute outcomes ratings are taken by using the rules explained in Section 3.1.2. These median values of BIM outcomes/BIM attribute outcomes ratings are equal to the composite values of BIM attributes which are given in Table 27. Detailed explanations are given below for each BIM outcome and BIM attribute outcome.

ARCH D/STR D/BS D-Architectural, Structural and Building Services Design and C-Construction					
BIM A1.1				BIM A2.1	BIM A3.1
ARCH D2-1	STR D3-1	BS D3-1	C1-1	BIM A2.1-a	BIM A3.1-a
ARCH D2-2	STR D3-2	BS D3-2	C1-2		
ARCH D3-1	STR D3-3	BS D3-3	C1-3		
ARCH D3-2	STR D3-4	BS D3-4	C1-4		
ARCH D3-3	STR D4-1	BS D4-1	C2-1		
ARCH D3-4		BS D4-2	C2-2	BIM A2.1-b	BIM A3.1-b
ARCH D3-5			C2-3		
ARCH D3-6	STR D4-2	BS D4-3	C2-4		
ARCH D3-7			C2-5		
ARCH D4-1			C3-1		
ARCH D4-2	STR D4-3	BS D4-4	C3-2	BIM A2.1-c	BIM A3.1-c
ARCH D4-3			C3-3		
ARCH D4-4			C4-1		
ARCH D4-5	STR D4-4	BS D4-5	C4-2		
ARCH D4-6			C4-3		
ARCH D4-7			C4-4	BIM A2.1-d	BIM A3.1-d
ARCH D4-8	STR D5-1	BS D5-1			
ARCH D4-9			C4-5		
ARCH D5-1					
BIM A1.2				BIM A2.2	BIM A3.2
BIM A1.2-a				BIM A2.2-a	BIM A3.2-a
BIM A1.2-b					BIM A3.2-b
BIM A1.2-c					BIMA3.2-c

FM-Facility Management		
BIM A1.1	BIM A2.1	BIM A3.1
FM1-1	BIM A2.1-a	BIM A3.1-a
FM1-2		
FM1-3		
FM2-1	BIM A2.1-b	BIM A3.1-b
FM2-2		
FM3-1		
FM3-2	BIM A2.1-c	BIM A3.1-c
FM4-1		
FM5-1		
FM5-2		
FM5-3	BIM A2.1-d	BIM A3.1-d
FM6-1		
FM6-2		
FM7-1		
BIM A1.2	BIM A2.2	BIM A3.2
BIM A1.2-a	BIM A2.2-a	BIM A3.2-a
BIM A1.2-b		BIM A3.2-b
BIM A1.2-c		BIMA3.2-c

Figure 22 Ratings of BIM outcomes and BIM attribute outcomes

Ratings of each BIM outcome and BIM attributes outcomes are determined based on the assessment report of Company E. It includes the assessment findings and collected evidences for BIM outcomes and BIM attribute outcomes which are summarized below.

Level 1 – Performed BIM for ARCH D, STR D, BS D, C and FM:

BIM A 1.1 Performing BIM for ARCH D, STR D, and BS D:

ARCH D2-1 Draw up space program and requirements are developed (areas, volumes and etc.): They collect space requirements from the client. They develop space program and requirements based on technical specifications documents which are sent by the client. BIM is not included in this process.

ARCH D2-2 Programming: Design performance is assessed in terms of spatial requirements: They check design performance in Conceptual Design. For example, they controlled the distances between the check-in desks and baggage conveyors.

They also conduct site analysis. For example, in another project in Europe, metro is located just near the building. Therefore, BIM is used for looking at the foundation locations and its possible effects on the metro line.

ARCH D3-1, ARCH D3-2, ARCH D3-3, ARCH D4-2, ARCH D4-4, STR D3-1, STR D3-4, STR D4-1, BS D3-1, BS D3-4 Design authoring*:* Design work flow of Company E is composed of four steps which are 1-Concept Design, 2-Schematic Design, 3-Detail Design, and 4-Construction Documents. The most important issue in Construction is the collection of all models and specifications. Issued for Construction is a package of models and facility information such as drawings, specifications, and standards. Models are created at LOD 300/ LOD 350 in Issued for Construction.

They have a large BIM team in all of their projects. BIM is included in the Concept Design. Later, in the following processes model is shared with stakeholders. They develop models at LOD 100/LOD 200 in Concept Design. Architectural Detail Design is modeled at LOD 300.Autodesk Revit is used for creating models in Architectural, Structural and Building Services Design since most of their customers and their sub-contractors choose Autodesk as the software vendor. However, they do not want to use Revit in Building Services Design. Therefore, in some cases, they create building services models in Autodesk Revit and import that model into Bentley in IFC format. However, they faced with interoperability problems in this procedure. There is a calculation cycle in Building Services Design; when the Architectural Design is changed, calculations of Building Services Design are performed again.

ARCH D4-1 Design review: Design review is conducted for the global model created: They review their models.

ARCH D3-4, ARCH D4-3, STR D3-2, STR D3-3, BS D3-3 and BS D4- 2 3D coordination: During design stage, many clashes are resolved by conducting 3D coordination. 3D coordination between architectural and structural models is conducted in the design phase. However, conflicts of building services design are usually resolved in construction stage since building services designs are usually too complex. Since the number of clashes can be too many in an airport project, first of all they reduce the number of clashes from thousand to hundreds. Then, detailed clashes are resolved at the construction stage. Navisworks is used for 3D coordination since Revit and Navisworks belong to the same software vendor.

ARCH D4-5, STR D4-3, BS D4-3 Cost estimating: They estimate cost in two ways. This first way is calculating based on the quantity take-offs, and the second way is cost calculation based on facilities' systems. They are conducting 5D cost estimation in design phase. They create quantity take-off in Concept design for verification of the designed elements. For example, in one of their projects, they took quantity-off for facades. Revit is used for calculating quantities, sometimes they also benefit from Revit's plug-in for quantity take-offs. Units of quantities are defined in BEP. For cost estimation they use Dynamo. They tried to use Vico, but it was hard for them to make work break down of structures of models which are compatible with the tool.

ARCH D4-6, STR D4-4, BS D4-4 Phase and 4D planning: They use MS Project and Primavera for creating work schedules. Then work schedule is integrated with models in Navisworks to create simulations. They also use Synchro.

ARCH D4-8, STR D4-2, BS D4-5 Engineering analysis and ARCH D4-9 Sustainability analysis: In an airport project, models were given as an input to another software which is used for pedestrian comfort analysis. Wind effect for roof is calculated. In one of their projects, they tried to decrease the amount of sunlight coming inside the airport by arranging the facades ratio. According to them, temperature inside the airports in Turkey can be reduced by decreasing the amount of sunlight inside the airport. For energy analysis, a plug-in for Revit is used. Additionally, they are using EnergyPlus. They conducted LEED analysis for two of their airport projects.

ARCH D5-1, STR D5-1 and BS D5-1 Record modeling: They create As-Built models.

ARCH D3-5 Code and compliance checking is performed: They conducted rule checking in one of their projects by using Dynamo.

ARCH D3-7 An application for a building permit is submitted: As they usually involved in the projects after the bidding, application for a building permit is usually submitted by their clients.

ARCH D4-9 Tender documents including BIM protocols are created: They receive BIM protocols from their customers and create BIM protocols in tender documents for their designers/subcontractors.

BIM A 1.1 Performing BIM for C:

C1-1 Qualified parties with BIM capability who will be invited to bid on a work package are identified: They invite qualified parties with BIM capability.

C1-2 Proposals for bid including BIM costs are prepared by qualified parties: Some of the design firms, who are working with BIM, want to include only costs for editing models in the contracts. However, Company E defines all required BIM costs in their contracts at the beginning of a project.

C1-3 Proposals are reviewed and BIM using constructor/subcontractors are selected based on the criteria set by the staffing plan: They work with the subcontractors who use BIM.

C1-4 Contracts including BIM clauses are formalized: Company E defines all required BIM services for design in their contracts. Their designers are responsible for creating the design at LOD 300/LOD 350, as well as creating shop drawings. Their designers are required to share the models weekly for coordination. In most of their projects, their sub-contractors are responsible for all design work. On the other hand, Company E is responsible for the designs after the receive them according the contracts with their customers. Therefore, they need to get professional intended.

C2-1: Phase and 4D planning: Construction sequencing is created: They are conducting phase and 4D planning in tendering. For example, in one of their projects, they created 4D simulations which show monthly work progress based on each discipline and zone.

C2-2 Site utilization planning: BIM is used to graphically represent facilities on site which can include labor resources, materials with associated deliveries, and equipment location: They benefit from BIM for site utilization. According to phase and 4D planning, they conducted logistics studies. For example, in one of their projects, 4D is used for locating the cranes.

C2-3 5D cost estimating is used for developing the budget: They create 5D cost estimation in construction.

C2-4 Shop drawings are created using BIM: They have shop drawings which are the updated versions of models based on the change requests coming from the site. In Turkey, combination of shop drawings is usually called as As-Built. However, it is not the actual As-Built as these should include updates from the construction phase.

C2-5 Status/progress monitoring is visualized from site data: In one of their projects, they use the program called Viewpoint. Aconex Field and Autodesk Field software applications are used for data gathering from site. They collect data from site by using laser scanning as well. Progress monitoring is easy on the high level but very difficult in detail. In an airport project there are many zones, while one work is conducted in a zone, another work is done in another zone. Because of that, it is even difficult to track progress manually. Therefore, it is partially conducted.

C3-1 Resources are acquired and inventory is managed in accordance with inventory information gathered from integrated ERP and BIM tools: Models are not integrated with ERP tools and procurement software applications.

C3-2 Digital fabrication: Digital fabrication is facilitated: Digital fabrication is conducted from the model, especially for steel elements. Digital fabrication can also be facilitated for precast elements. However, in order to do this, design phase is required to be performed in accordance with modular construction. In order to have modularity, architect needs to think this way.

Benefits of BIM are important when there are time and contractual constraints. Since each of their projects has unique design, it is hard to solve the problems which are faced during the construction. In order to solve these problems, there are not any repeated patterns. For instance, in a hotel every room and every building element might be similar, so modeling and construction of such buildings becomes easier. It takes up 3-4 km area from one side to the other side of airports in Building Services Design and it isn't symmetric all the time.

C3-3 The distribution priorities are determined based on 4D plan: They conducted logistics studies by using BIM.

C4-1 Daily work is executed based on 4D plan: Daily work is conducted based on 4D plan.

C4-2 3D location identification: Physical locations of elements on site are pinpointed for construction layout: Within the logistics studies, they identified where the columns should be located by using BIM.

C4-3 Facility is constructed by using BIM: In construction they use their models. If there is a change request from professionals in the field, revisions are made on the models which are stored in common data environments.

C4-4 Quality assurance is conducted: They are conducting QA/QC by using BIM. Laser scanning is used for collection of data to conduct quality assurance and existing conditions analysis of a facility. They tried to identify deviations in the facades of a skyscraper in one of their projects.

C4-5 Operation data is handed over to the owner with BIM: They are doing testing & commissioning as a contractual requirement and they have Defect Liability Periods (DLP). They give a package of information including models to the client at the handover stage. For one of their airport projects, which does not include BIM, they started modeling from scratch by looking at it from the FM's points of view. They started to model just 4-5 months before the operation of the airport.

BIM A 1.1 Performing BIM for FM:

FM1-1 Asset management: Financial decision making, short term and long term planning and generating work orders schedules are assisted via integrating record models with asset management systems*:* Asset data is linked to the model. In one of their project, there is mobile equipment which are ninety coolers. In winters, these coolers are taken out and in summers they are taken in the airport. Facility managers could not decide whether these coolers should be defined in the asset management system or not. These kind of small issues create bigger problems later. In reality, ninety coolers are valuable in terms of asset management.

FM1-2 Space management: Space distribution, management and tracking is utilized by integrating record models and spatial tracking software*:* Space management is established by using BIM. Since airports are the places where operations are critical and dynamic, facility manager should be determined. Systems require to be updated within a specified short period of time.

FM1-3 Disaster planning and management: Critical building information is made available to the responders by integrating record models and BMS which allows clear display of emergency locations: Disaster planning and management is thought as the next 2^{nd} and 3^{rd} goal. It is required to have Operational Readiness Transfer (ORT). It can be built on top of GIS, since there is routing in GIS.

FM2-1 Physical performance information and operations historical data reviewed via integrating record models and facility management systems: In one of their airport projects, BIM 360 is used. Employees who are working in facility management follow the model through their tablets. It is used for tracking models, and for quality control purposes.

FM2-2 O&M scheduling is planned by integrating record models and facility management systems such as BAS and CMMS: In one of their airport projects, integration of IFC, Ecodomus and GIS is enabled. Model information and object IDs are matched. A work order, which is opened by using IFC, is made visible in Ecodomus. Additionally, it can be traced when the work order is opened and closed.

FM3-1 Facility points/areas are selected for collecting operations data through sensors: These issues are not usually thought clearly in facility management.

FM3-2 Operations data, which is collected through sensors, is stored, classified, or simplified in record model integrated with BAS in order to be used by other functions: They do not have integration with BAS, yet. But it is an important point for them to have.

FM4 -1 Monitoring information for identifying problem area is compared with critical or expected performance values which are attached to models*:* Expected performance values are not stored in the model.

FM5-1 Root-cause analysis is performed by using the model to understand the problem*:* Root-cause analysis is performed by integrating the models and CMMS.

FM5-2 Technical solution for the problem is designed by using the model: Usually, it is not specified how a window on the roof is required to be changed, when it is broken. For example, lights of airports are usually fixed at high altitudes such as 18 meters high. Thus, it is required to have instructions for cleaning and changing them.

FM5-3 Implications of the problem solving plan are analyzed by using the model: In one of the airports in Turkey, the doors which leads to the roof have not been built, and these doors needed to be constructed later. Such issues can be eliminated when models are used for design check.

FM6-1 Decisions for selecting problem solution plan are made via integrating models and facility management tools/asset management tools: Decisions are not made based on the model.

FM6-2 Services and resources for implementing the plan are allocated by integrating models and facility management tools: Another important topic for airports is management of spare parts. IDs in accounting systems can be very different than the object IDs in BIM. Additionally, sometimes changes are not only required to be reflected to the model, but to the documents and technical specifications. However, they are not representing them in the models.

FM7-1 Performed O&M tasks are reflected to the model: After the system is maintained, as there will be data coming from the facility, it is required to think about the method and frequency of transferring the updated data into the system. The ideal situation would be that employees can access the system easily through GIS. GIS is useful to support someone, who knows nothing about BIM. They want to change the data by clicking an asset from the tablet. They can immediately reach to the asset/element on which they are working at a point in time. They want to solve this problem by using GIS.

BIM A 1.2 BIM Skills:

a) Staff with BIM trainings and/or BIM experience are employed,

b) Employees are supported in taking BIM trainings, and

c) BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged.

They provide internal training. Most of their architects and civil engineers have attended to the certification program which is held in one of the technical universities of Turkey. They nearly train 15 to 20 architects and engineers in a year. Including the intern, the average number is 60.

First of all, they give a brief instruction about the company's work flows and the design procedures. They usually want interns to learn modeling by experiencing real projects rather than making them to follow instructions. Interns create models in LOD 200-300 level for an existing project. They are given CAD drawings from architectural, structural and building services design disciplines. Interns create models by using the drawings and required technical specifications. By this way, interns learn not only how to model by using BIM but also design work flows and required interpretations for creating a model.

Level 2 – Integrated BIM for ARCH, STR, BS D, C and FM:

<u>BIM A 2.1 BIM Collaboration:</u>

a) <u>Requirements and strategies are defined for supporting BIM collaboration between internal and external parties,</u>

b) <u>Requirements and strategies are defined for exchanging the model and the facility information between phases and processes,</u>

c) <u>Defined BIM collaboration strategies are implemented,</u>

d) <u>Defined exchange strategies of the model and the facility information are implemented.</u>

They have standards and procedures written for BIM collaboration. Some details are defined such as how frequently and in which work flows, model sharing is required. All modeling and BEP work flow is defined within the context of their ISO 9001 certification.

They use Aconex and Basecamp programs for communication with their clients. They have hybrid system which is composed of cloud and server. A project takes up 2-3 terabytes on average. They use an in house cloud software application for data exchange. It is a software application based on Egnyte and specifically written for Company E. The cloud is a storage system, which has pre-defined authorizations, enables storing and exchanging big models. They can give some specific authorizations to sub-contractors. Sub-contractors can create their own files and folders. Automatic notification is delivered to all users when an update is made on the models. They have versioning system for models in design files and folders. They can add comments on models in the form of pop ups. They take backups at the file level. They want to use Autodesk 360. They create to do lists at Basecamp, and if it is necessary, they can also share these lists. They also send instant messages. They can see everything about a subject. For instance, if there is a conversation about a column, anyone can write and see comments under that column. This enables searching within the project.

They make less coordination meetings in the design phase. They make coordination meetings three times in a month in the construction phase. Weekly updates are done on the model in the construction phase.

There is not a central model. There is a reference model and all work is done according to this reference model. It is required to finish the modeling at a point and to share it with other stakeholders. Sometimes, some teams make a number of changes and they don't reflect these changes to their model. Solved problems are not seen on the model that's why ghost clashes show up. These problems arise since they don't either update or share the model.

<u>BIM A 2.2 Interoperability:</u>

<u>a) Interoperable formats are made available and used to support data exchange between BIM software and other construction software applications.</u>

In one of their airport projects in Europe, they used open source formats because client wanted to use data formats of Building Smart. They saved and delivered clash data in BIM Collaboration Format (BCF), not in Navisworks format.

If clients do not give preference about formats, clash data is usually saved in .xlsx, .pdf or in Navisworks' own format as viewpoints. So when clients import the data into Navisworks, they can directly see the clashes. They have projects in which they saved the clashes as .html and .xml.

Level 3 – Optimized BIM for ARCH, STR, BS D, C and FM:

BIM A 3.1 Corporate-wide BIM Deployment:

a) Model is used for all processes and embraced by all team members,

b) Required facility information for different processes are extracted from the model and provided for the use of all team members,

c) Change management and synchronization of the model are established and the model updates are tracked, and

d) BIM objects and facility information are collected in a library for reusing this information on future projects

They have constructed the GIS infrastructure especially for QA/QC and health and safety processes. For an airport, they built a system, which is compatible with AutoCAD, on top of the GIS infrastructure. However, there is a big interoperability problem between GIS, BIM and AutoCAD. ArcGIS has created a plug in which is very useful for solving the interoperability problems. According to them, GIS is useful for collecting data in big areas. However, it is problematic inside the facility. It is difficult to collect data based on floors or assets. They also looked at the new infrastructure which is called Digital city. It is a parametric software language similar to Python. Since they tag the links as well, it is easy to follow them in the database by using this language.

Usually there are control engineers on site. Their responsibilities are to walk around the construction and record the problems which are important. They usually use MS Excel to record these problems and report them to the technical office. If it is required to report a problem immediately, they use WhatsApp. Although it is a quick solution, the problem is resolved without being recorded. Risk analysis cannot be conducted and feedback cannot be gathered. Instead of these methods, if a tool is used for the recording and reporting the problems on site, problems can be resolved immediately such as the snag lists.

They have change management for models. There are a track sheets for every delivery of the model. Which changes are done based on which revision requests can be seen in there.

They have libraries that the most frequently used objects are kept. However, most of the objects are required to be revised before almost every new project since, naming of objects is different in those projects.

Lost time incident is the measure of the time an employee does not attend to work after an incident. The incidents have categories according to their severity and a risk calculation methodology is established according to historical data. In one of their projects, which was 18 billion hours' project and sixty-five thousand people were working on site, no incident has happened. A shopping mall building needs approximately nine hundred thousand hours to be completed.

BIM A 3.2 Continuous BIM Improvement:

a) A feedback mechanism is created to identify common causes of variations in BIM usage,

b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified, and

c) An implementation strategy is established to achieve BIM improvement objectives.

They usually attend conferences for following technical improvements. They follow and usually attend Autodesk's training in Turkey. There was a workshop for both white and blue collar employees. It is called build together and they share their experience and knowledge in those two days.

4.5 Validation of the Exploratory Case Study and Multiple Case Studies

We validated the case study results by discussing the assessment findings and ratings with the interviewees. In order to do that, we shared the findings and ratings of each assessment with the interviewees. Additionally, we asked them to fill an online questionnaire, which is composed of five questions and presented in Appendix G. Another method for ensuring the validity can be comparing the results of our assessment with the results of another assessment performed in the same company by using one of the existing models in the literature. However, we were not able to perform such a comparison due to lack of information about details of assessment methodologies of those methods in the literature.

We asked four different questions to the interviewees in each Company and requested them to rate each question by using Likert scale (1-5). One of the questions is asked to learn whether the interviewees used a similar model to BIM-CAREM before, or not. Since it is a Yes/No question, we did not resent that question in Figure 23. Answers to the four questions by each company are given in Figure 23. Detailed answers are given in Appendix G. Opinions of interviewees are summarized below.

Exploratory case study with Company A: Exploratory case study is conducted with two interviewees in Company A. One of them is the BIM manager of the company and the other interviewee is working as MEP lead designer of the company. Both of the interviewees have not experienced a similar assessment before.

Company A's BIM capability level of Conceptual Planning is Level 1-Perfomed BIM; and level of Architectural Design, Structural Design and Building Services Design are found as Level 2-Integrated BIM. When the findings and ratings are discussed with the interviewees, both of the interviewees have said that BIM-CAREM has identified the same BIM capability level as they have thought before. According to their answers, which are presented in Figure 23, BIM-CAREM can identify BIM capability of the AEC/FM processes. Furthermore, lead MEP designer emphasized that findings are helpful to understand what have to be done in order use BIM more efficiently, especially in design processes. According to MEP lead designer, BIM-CAREM can be utilized in different organizations for identifying BIM capability of AEC/FM processes. BIM manager mentioned that it is very useful for having BIM capability of individual processes and understanding the relationships between the processes.

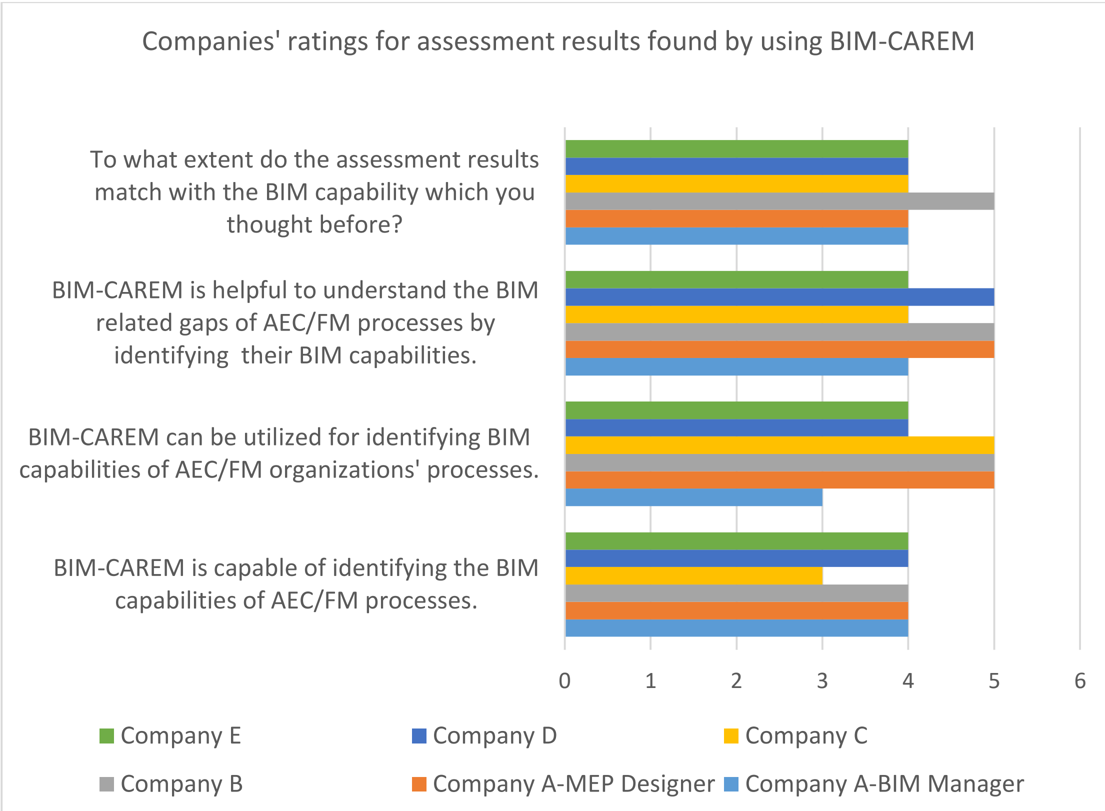

Figure 23 Validation ratings of assessment results found by using BIM-CAREM

<u>Case study 1 with Company B:</u> The assessment has been conducted with a group of 5 interviewees who are managers, civil engineers, and designers of the Company B. None of them have seen and used a similar assessment model before.

Company B's BIM capability level of Structural Design of Steel Frames and Structural Design of Reinforced Concrete Frames are found at Level 2-Integrated BIM. We discussed the findings and ratings of the assessment and an online questionnaire is applied to the interviewees for validating the results of the assessment. Their answers to the questionnaire are presented in Figure 23. They usually answered the questions with general consensus. All of the five interviewees agreed that resulting BIM capability level matched with the existing BIM capability level of Structural Design of Steel Frames and Structural Design of Reinforced Concrete Frames. BIM-CAREM was able to capture the existing different practices in Structural Design of Steel Frames and Structural Design of Reinforced Concrete Frames. For example, while steel frames can be produced from models, reinforced concrete frames cannot be manufactured from models. Improvement suggestions can be derived in order to eliminate the gaps in the existing practices. Therefore, managers of the company mentioned that findings of the assessment are useful for understanding BIM related problems in their existing processes. They also mentioned that the model is very practical to use and easy to understand. According to the Figure 23, they agreed that BIM-CAREM can be used in the AEC/FM industry.

Case study 2 with Company C: BIM capability assessment of Company C is carried out with the owner of the company who is an architect. Interviewee has not seen and used a similar model before.

Company C's BIM capability level of Architectural Design is Level 1-Pefomed BIM. We discussed the results of the assessment and an online questionnaire is applied to the interviewee. Answers of the interviewee for the questions are presented in Figure 23. At the beginning of the assessment, interviewee stated that they have never worked in a project which includes BIM as contract requirement. Therefore, there is not an external drive for adopting BIM in Company C. On the other hand, they use BIM within the company for their own benefit. According to the opinions of the interviewee, BIM-CAREM is useful both for the companies who are beginners in BIM and would like to use BIM more efficiently. It is stated that the assessment creates awareness about how to use BIM in specific AEC/FM processes. According to Figure 23, the assessment results matched with the interviewee's previous opinion about capability level of Company C's processes. Moreover, interviewee agreed that BIM-CAREM can be used in AEC/FM industry for assessing BIM capabilities of processes/phases.

Case study 3 with Company D: BIM capability assessment of Company D is carried out with one interviewee who is the architect and the BIM supervisor of the company. Interviewee has not experienced such an assessment before.

Company D's BIM capability level is identified at Level 3-Optimized BIM for Construction. We discussed the results of the assessment and an online questionnaire is applied to the interviewee. Answers of the interviewee for the questions are presented in Figure 23. According to the results of the assessment, BIM supervisor of the company thought that the resultant BIM capability level of their construction processes are meaningful and are same as the BIM capability level which interviewee had in mind at the beginning of the assessment. Although design processes are not included in the context of the assessment, we needed to understand how BIM is used in their design processes. The reason for this is, BIM utilization in the construction phase is affected by how BIM is used in the design process. Specifically, since Company D's focus is to achieve handling progress payments from the model, modeling in design should be conducted according to this requirement. BIM-CAREM was found to be helpful to understand the BIM capability of specific processes. Moreover, it is said to be very powerful for identifying relationships of BIM utilizations between different processes. Interviewee found the assessment results objective and stated that BIM-CAREM can be used for identifying BIM capabilities of AEC/FM processes.

Case study 4 with Company E: BIM capability assessment of Company E is carried out with two interviewees who are the director of the engineering and design team and the BIM chief of the company. They came across with pre-tender assessment models; but they have not used these models before.

Company E's BIM capability is Level 3-Optimized BIM for Architectural, Structural and Building Services Designs, Construction and Level 1-Perfomed BIM for Facility Management. The findings and ratings are discussed with a questionnaire that is applied to the interviewees. Answers of the interviewees for the questions are presented in Figure 23. Both of the interviewees agreed that the assessment results are meaningful and same as their previous opinions about BIM capability of the processes/phases. Director of the engineering and design team found the assessment findings meaningful and helpful for solving BIM related problems. Both of the interviewees mentioned that conducting the assessment based on individual process and presenting the BIM issues for individual processes are very important for organizations, especially for large-scale organizations like them. Furthermore, since most of the client do not define company-wide BIM uses, they do not clearly state the BIM usages in their BIM protocols which are sent to the Company E. Thus, since BIM-CAREM also presents results with respect to BIM uses, they found the assessment results informative. According to the Figure 23, they both agreed that AEC/FM organizations can use BIM-CAREM for assessment of their processes.

4.6 Discussions

As stated in the previous sections, second version of BIM-CAREM is applied to Company A for conducting an exploratory case study and third version of BIM-CAREM is tested with multiple case studies in four different AEC/FM companies.

We applied BIM-CAREM in five different organizations including the exploratory case study. A summary of case study descriptions and findings is presented in Table 29. We tested BIM-CAREM in different types of firms with different sizes. For example, these companies are engineering and design firms, architectural design firms, and constructors. We evaluated different project types and different frame types in these companies. Metro projects, airport projects, sports facilities such as stadiums, buildings such as hotels and hospitals are assessed. In order to understand the difference between BIM practices in companies who are using BIM and firms who are not using BIM, we selected BIM mandatory projects and projects without a BIM contract requirement. We assessed company processes in all of the facility life cycle stages which are architectural, structural and building services designs, construction, and facilities management. Therefore, we evaluated BIM related processes of these phases as can be seen in Table 29. Conceptual planning is evaluated only in Company A and its BIM capability is identified as L1-Performed. Architectural design is evaluated in Company A, Company C and Company E and their capabilities are found at L2-Integrated, L1-Perfomed, and L3-Optimized, respectively. Structural design processes of Company A, Company B and Company E are identified as L2-Integrated, L2-Integrated, and L3-Optimizied, respectively. Building services design is evaluated in Company A and Company E and their capabilities are found at L2-Integrated and L3-Optimized. Applicability of BIM-CAREM in assessing construction processes is tested in Company D and Company E of which L3-Optimized and L3-Optimized BIM capability levels are identified, respectively. In Company E, we also assessed Facility Management processes and its BIM capability is identified at L1-Perfomed. In Company B, structural design of steel frames and structural design of reinforced concrete frames are evaluated. Although there are some differences in their design practices, both of them are at L2-Integrated. Information about case studies and resulting capability levels are summarized in Table 29.

According to the BIM capability assessments in design firms, BIM is mostly used in the detailed design processes. Most of the base practices of the detailed design processes are performed by using BIM. Based on the BIM capability assessment in construction and facility management phases, we can conclude that more processes are required to be performed by using BIM in these phases. Some examples of construction processes which includes BIM use are, phase and 4D planning, and digital fabrication.

All of the interviewees in five companies emphasized that it is very hard to find an engineer and/or an architect who have advanced level of BIM skills. While some companies prefer to hire employees with work experience and BIM experience or skills, some of them prefer to hire new graduates or less experienced employees. For example, company B said that they prefer to hire employees with intermediate level of experience and give them internal trainings regarding their own work flow and BIM usage. In most of the companies, peer-leaning is encouraged for increasing BIM skills of the employees. We have observed that, BIM trainings become more important as the employee numbers increases in an organization.

Design firms are forced to use BIM collaboration procedures and tools which are preferred by the general contractors. Eventually, flexibility is a competitive advantage for the design firms to be awarded tenders from the general contractors. It is observed that general contractors created their own standards for modeling, collaborating, and model and facility information sharing since they want their designers/sub-contractors to follow their procedures. For example, Company D created a modeling guideline for creating models which enable to obtain accurate quantity take-offs. They share this guideline with their design sub-contractors. It is observed that BIM uses such as, energy analysis in design, 4D planning and digital fabrication in construction, as well as asset management in FM, forces organizations to use interoperable formats.

Contractors, who are Companies D and E, use BIM from initial phase to final phase. Thus, they identified at BIM Capability Level 3- Optimized BIM. We observed that evaluating BIM usage at enterprise level is easier for constructors. Even though the companies, which are found at BIM Capability Level 3 - Optimized BIM within the context of the multiple case studies, are following new trends and technologies regarding BIM and having regular innovation meetings, they do not have written procedures for identification of problems preventing the BIM usage, development of solutions to these problems, and methods of implementations for such solutions in the company.

Based on the case study results and expert feedback, the research questions of this study are discussed below.

RQ1: How the BIM processes of an AEC/FM organization can be formally assessed?

RQ1.1: What are the key processes that should be assessed for covering all facility life cycle phases?

RQ1.2: What BIM practices and outcomes should be available for each process of facility life cycle?

First of all, both of the Building PRM and BIM PRM are developed based on the requirements defined in ISO/IEC 33004 (ISO/IEC, 2015). The facility life cycle phases, which are included in the context of this research, are determined based on the RIBA plan of work (RIBA, 2013). Thus all of the important facility life cycle stages, which are conceptual planning, design, construction and facility management, are covered. Furthermore, key AEC/FM processes are identified based on two technical reports (VTT, 1997) (PennState CIC, 1990). Therefore, key processes of each stage are covered in Building PRM. Definitions of each AEC/FM process are created based on the process models given in the form of IDEF diagrams in these technical reports. BIM related processes are marked. BIM outcomes of these BIM related processes are created based on the BIM uses identified from literature.

Table 26 Demographic information of companies and overview of exploratory and multiple case study results

Case	Type and Size	Evaluated Project Type	Evaluated Frame Type	BIM Contract Req. (Y/N)	Evaluated Phases/Processes	Identified BIM Capability Levels
Exp. C - Company A	Engineering and design firm More than 200 white collar employees	Metro projects including tunnels, stations, etc.	Reinforced concrete	Y	P: P2, P3, P5, P6 ARH D: D2, D3, D4, D5 STR D: D3, D4, D5 BS D: D3, D4, D5	P: L1-Performed ARCH D: L2-Integrated STR D: L2-Integrated BS D: L2-Integrated
CS 1- Company B	Engineering and design firm Less than 50 white collar employees	Buildings and sports facilities such as stadiums	Reinforced concrete and steel	Y	STR D: D3, D4, D5	STR D: L2-Integrated STR D: L2-Integrated
CS 2- Company C	Design firm Less than 10 white collar employees	Buildings such as hotels	Reinforced concrete	N	ARCH D: D2, D3, D4, D5	ARCH D: L1-Performed
CS 3- Company D	Constructor-Healthcare Management Group More than 200 white collar employees Within top 50 based on 2016 ENR Top 250 Constructors	Hospitals	Reinforced concrete	Y	C: C1,C2, C3, C4	C: L3-Optimized
CS 4- Company E	Constructor More than 2500 white collar employees Within top 100 based on 2016 ENR Top 250 Constructors	Airports	Reinforced concrete and steel	Y	ARH D: D2, D3, D4, D5 STR D: D3, D4, D5 BS D: D3, D4, D5 C: C1, C2, C3, C4 FM: FM1, FM2, FM3, FM4, FM5, FM6, FM7	ARCH D: L3-Optimized STR D: L3-Optimized BS D: L3-Optimized C: L3-Optimized FM: L1-Performed

Secondly, according to the results of the expert reviews and exploratory case study, some terminologies are changed in the process definitions. Each BIM outcome is tagged with one of the two values namely “Essential BIM Use” and “Enhanced BIM Use” as defined in National BIM Guide for Owners (NBIMS, 2017). Initially, we planned to use this tagging for determining weights of BIM outcomes by assigning more weight to essential BIM uses. Then these weights could have been used for aggregating BIM attribute outcomes to single attribute assessment values, instead of using median of the values as we have done. However, we were not able to use these weights since the report does not include comprehensive BIM uses to cover all BIM outcomes we have identified in our model. Therefore, we assumed the weights of all BIM outcomes are equal.

Considering the results of the multiple case studies, we can conclude that we have not face with any process performed in the AEC/FM organizations which has not been defined in the BIM PRM. Similarly, no redundant process is identified in BIM RPM. Since BIM outcomes are defined by using BIM uses identified in the literature, they were understood by the interviewees when we asked the questions. We developed specific evaluation questions for assessing achievement of the selected process’s BIM outcomes. However, some of the questions are similar for different processes. For example, while assessing the Performing BIM attribute for “Make Architectural Detail Design” and “Make Structural Detail Design” we asked similar question such as “How do you create Architectural/Structural models?” This makes the evaluation period longer and repetitive in some cases. On the other hand, we did not face with any ambiguity when assessment questions are asked to interviewees.

We observed that BIM outcomes of the conceptual planning, architectural, structural and building services designs, and construction processes are defined in detail. However, we had to define some of the BIM outcomes at very high level such as asset management and space management. This is because the facility management processes are not defined in detail in the CIC’s technical report (PennState CIC, 1990).

RQ2: How general can a formalized assessment approach be for assessing BIM capability of AEC/FM organizations?

RQ2.1: What can be the assessment levels of BIM capability and BIM attributes for gauging/evaluating BIM capability of AEC/FM organizations’ processes?

RQ2.2: How suitable is the BIM-CAREM to be used for the purpose of identifying AEC/FM organizations’ BIM processes capability?

BIM MF is developed based on the principles of ISO/IEC 33003 (ISO/IEC, 2015). BIM capability levels and associated BIM attributes are created based on the keywords identified from BIM uses via natural language analysis. Therefore, measures are created based on established standards and analysis. Feedback from expert reviews showed that, created BIM capability levels, BIM attributes, and BIM attribute outcomes are comprehensive. All of the BIM uses identified in the literature are covered by the assessment measures.

According to the exploratory case study and multiple case studies, we did not observe any major difficulty in the application of BIM-CAREM for identifying BIM capability of different AEC/FM processes. We identified that assessment of BIM Skills which is one of the attributes of BIM Capability Level 1, is repetitive when different processes are assessed. We thought that measuring

Continuous BIM Improvement is also repetitive when it is assessed for all individual processes. Therefore, BIM Skills and Continuous BIM Improvement can be measured at the organization level or more detailed assessment questions should be defined to evaluate different applications in individual processes.

BIM Collaboration in Conceptual Planning is limited to document management, since models are not created at this stage. Therefore, measuring BIM Collaboration in Design and the latter stages is easier. We had some difficulties in the measurement of BIM Collaboration due to flexibility requirements of Turkish construction companies for continuing their existence in the market. Flexibility necessity forces designers/sub-contractors to be highly-adaptive to new situations and prevents them to have established standards and practices, especially for collaboration.

We did not face any difficulty in measuring Interoperability, since in most of the stages interoperable formats are used. For example, point clouds which are collected though laser scanning in Conceptual Planning and IFC format which are used for sharing models in design stage.

We have identified some differences in assessments of BIM attribute “Corporate-wide BIM Deployment” in engineering and design firms versus in general contractors. Eventually, we addressed this problem by modifying one of its BIM attribute outcomes based on an expert feedback during one of the expert reviews. Since engineering and design firms only have design and engineering processes, enterprise level BIM usage is hidden. BIM usage at the enterprise level is more dominant in general contractors. According to an expert feedback, some of the BIM attribute outcomes of Corporate-wide BIM Deployment such as “BIM objects and facility information are collected in a library for reusing this information on future projects” are more meaningful at the project level. However, we did not face any difficulty in observing this BIM attribute outcome.

Due to contractual constraints, organizations cannot perform some of the processes by using BIM. For example, models are not included in the application for a building permit since they are not requested by the governmental organizations. For such kind of situations, since we could not gather enough evidence to give a rating, we gave N/A for the related BIM attributes/BIM attributes outcomes.

During the case studies we asked the strengths and the weaknesses of the assessment model to the interviewees. Table 30 presents the strengths and weaknesses of the model with respect to each company. Major strengths of BIM-CAREM are identified as, model enables AEC/FM processes based BIM capability assessment and it allows users to identify the relationships/dependencies between the processes. Only one of the experts emphasized that the model does not evaluate the sub-processes of AEC/FM processes. However, including sub-processes may increase the complexity of BIM capability assessments. Therefore, we excluded the sub processes such as modeling strategy.

Interviewees in Company A, Company B, and Company C thought that BIM-CAREM is powerful in creating awareness about BIM. According to Company A and Company B’s interviewees, it helps to identify BIM related problems in different processes and can help to create BIM improvement paths. According to interviewees of Company E, listing BIM uses and defining BIM outcomes is very important for the firms who do not define how to use BIM within their companies.

Table 27 Strengths and weaknesses of BIM-CAREM

Respondents	Strengths	Weaknesses
Company A	It helps to better understand what needs to be done for using BIM effectively. Model enables process based BIM capability evaluation and looks at the relationships of the processes.	More assessment metrics can be defined. The model does not evaluate the sub-processes of processes.
Company B	It is a practical model, understandable, helps to solve the problem, creates awareness.	Terminology is required to be closer to construction industry. This is required to understand the specific problems of the Turkish construction
Company C	Model is useful for creating BIM awareness.	Terms in the model are required to be revised. Since Turkish construction industry is very complex, model may need modifications to use it in Turkey.
Company D	Model is applicable to all AEC/FM processes and does not separate processes from each other in terms of their importance.	Questions/issues regarding to governmental organizations such as municipalities can be added.
Company E	Model enables BIM capability assessments based on individual processes. BIM outcomes and BIM uses are considered in the model.	Model can be customized in terms of firm types.

According to Company B and Company C, major weakness of the model arises from the complex structure of Turkish construction industry. General contractors in Turkey have different requirements in different construction projects. This necessity forces sub-contractors to be highly-adaptive to new situations and prevents them to have established standards and practices within their companies. Moreover, processes differ based on the types of firms. For example, while engineering and design firms only includes conceptual planning and design processes, general contractors can perform all of the processes of facility life cycle stages. Thus, assessment requirements and capability levels of these different types of firms can be different. Therefore, flexibility and modularity of BIM-CAREM can be improved. On the other hand, we believe BIM-CAREM has a flexible structure that enables assessments based on specific processes. It can assess BIM capability of different types of firms as exemplified by the multiple case studies.

BIM-CAREM may need to be better adapted to Turkish industry, since we have the AEC/FM processes of BIM PRM based on the US and Finland standard processes. Although mostly there are universal standard and procedures in AEC/FM, different practices are being performed in local industries. Important BIM uses for Turkish construction industry and associated processes might be included in the model if any missing ones can be identified. According to the interviewees of Company D, governmental owners were not considered in the model development which can also affect the assessments, especially in facility management. BIM uses which are important in terms of governmental owners might be included in the model in the future.

4.7 Validity Threats

The validity of a case study denotes that to what extent the results are not biased by the researcher (Wohlin et al., 2012). According to Yin (Yin, 2003), there are four threats to validity in a case study. These are construct validity, internal validity, external validity, and reliability. We addressed each threat during the conduct of the case studies.

4.7.1 *Construct Validity*

Construct validity ensures correct operational measures for the concepts being studied. In order to address this problem, data triangulation is used (Yin, 2003). Triangulation is to use one or more approaches for data collection, sources of data and data analysis (Fellows & Liu, 2015). In this research study, data is collected from different sources of evidence which are interviews, direct observation and questionnaires. Furthermore, prior to each assessment, BIM-CAREM and its components are defined in detail to the interviewees, in order to eliminate the conflicts.

4.7.2 *Internal Validity*

Internal validity is applicable to case studies which have causal relationships. This threat may arise from investigator's inferences based on the interview. Questions, of which some examples are given below, are required to be answered (Yin, 2003):

- Is the inference correct?
- Have all the rival explanations and possibilities been considered?

Respondent validation is used for eliminating this threat (Fellows & Liu, 2015). As part of our case studies, informal checks are conducted for each appraisal. Findings and understandings of the interviews are shared with the interviewees for clarification.

4.7.3 *External Validity*

External validity deals with whether the findings of a case study are generalizable or not. It is stated that single case studies are poor in terms of generalizability (Yin, 2003). In order to eliminate this validity threat, we have chosen different samples by looking at three criteria which are as follows:

- Organization type and size,
- Facility type, and
- Structural frame type of facilities.

We have conducted five case studies in total. According to these three criteria, the chosen AEC/FM organizations are as follows:

- Design firm – Architectural, structural and building services design of metro projects including metro tunnels, stations and etc.,
- Design firm – Structural design of sports facilities such as stadiums and buildings,
- Design firm – Architectural design of buildings such as hotels,

- Constructor – Construction of hospitals and medical complexes, and

- Constructor – Architectural, structural, building services designs, construction and facility management of airports.

4.7.4 *Reliability*

Reliability of case study aims to reach the same findings and conclusions by following the same procedures described by an investigator who has conducted the case study (Yin, 2003).

In order to increase the reliability of the multiple case study, replication method is used (Fellows & Liu, 2015). Case study with Company B is replicated. Two weeks after conducting the case study, Company B has been visited again and 4 hours of time have been spent by asking the important interview questions again. Even though a new assessment is not conducted from scratch by a different assessor, the previously identified findings of the case study are observed again and verified.

CHAPTER 5

CONCLUSION AND FUTURE WORK

This chapter presents the summary of research, and theoretical and practical contributions in Sections 5.1 and 5.2, respectively. Limitations and future work is also discussed in Section 5.3.

5.1 Summary of the Research

First of all, systematic literature review is conducted to identify BIM capability and maturity models in AEC/FM domain. Eight models are selected, analyzed and compared based on the determined criteria. Analysis and comparison results are explained in Chapter 2, and they are also published in the review paper of Yilmaz et al. (2017).

A reference model for assessing BIM capability of AEC/FM processes, namely BIM-CAREM is developed based on the principles of ISO/IEC 33000 standard and modified iteratively via expert reviews and an exploratory case study. Two iterations are performed to reach the final version of BIM-CAREM. BIM-CAREM is composed of two dimensions which are process dimension and BIM capability dimension. Process dimension is represented by Building PRM and BIM PRM. BIM capability dimension is represented by BIM MF.

Building PRM and BIM PRM are developed based on the principles of ISO/IEC 33004 (ISO/IEC, 2015d). Building PRM includes a list of key AEC/FM processes which cover all facility life cycle stages namely Conceptual Planning, Design, Construction and Facility Management. Building PRM also includes definition of each process in terms of process purpose and process outcomes. Key AEC/FM processes of each facility life cycle stage are identified based on the two technical reports, namely, An Integrated Building Process Model (PennState CIC, 1990) and Construction Process Model (VTT, 1997). Process definitions in Building PRM are also created based on the IDEF diagrams of processes which are given in two the technical reports (VTT, 1997) (PennState CIC, 1990). Later, BIM related processes are marked and included in the BIM PRM. BIM outcomes are defined instead of process outcomes in BIM PRM. BIM outcomes of each process are defined based on the BIM uses which are identified from various resources in literature such as surveys, BEPs, and research articles.

BIM MF enables BIM capability assessments by having definitions of BIM capability levels, associated BIM attributes and the rating scale. BIM MF are created based on the principles explained in ISO/IEC 33003 (ISO/IEC, 2015) and by investigating the recurring keywords which are identified as a result of Natural Language Analysis on BIM uses.

The second version of BIM-CAREM is created by modifying first version of BIM-CAREM in accordance with the feedback gathered from Expert 1 who is working as the director of design and engineering team of an airport construction company. The major differences between the first and second version is that we added BIM attributes “BIM Skills” and “Corporate-wide BIM Deployment” to Level 1 and Level 3, respectively.

The third version of BIM-CAREM is created based on two expert reviews and an exploratory case study. Both of the experts are BIM consultants who are giving BIM consultancies to renowned companies in Turkey and in Canada. One of the experts focused on BIM process reference model and major modifications are performed in this model. BIM outcomes are marked based on two values “Essential BIM Use” and “Enhanced BIM Use” which are the terminologies defined in National BIM Guide for Owners (2017). The other expert suggested creating a checklist to be used during the assessments for making observations of assessment indicators easier. According to this feedback, a checklist is created which includes assessment indicators composed of Generic BIM Work Products and Generic Resources. Moreover, one BIM Attribute Outcome is modified based on the feedback of Expert 3. This BIM Attribute Outcome is “Model is used for all processes and embraced by all team members”. Exploratory case study was conducted with Company A which is an engineering and design firm. They are performing architectural, structural, building services and geotechnical designs of metro projects. The only difference between the exploratory case study and multiple case studies is the checklist usage. While checklist is not utilized for exploratory case study, it is used for collecting data during multiple case studies.

The third version of BIM-CAREM later approved via two expert reviews. One of these experts is the Expert 1 and the other is Expert 4 who is a civil engineer that gave consultancies in UK before. According to the feedbacks of Expert 1 and Expert 4, we recognized that most of their feedbacks have been addressed before. Minor modifications are performed such as adding a new Generic BIM Work Product which is “Company-wide BIM Execution Plan”.

After having approval of the third version of BIM-CAREM, applicability of final version of BIM-CAREM is tested through multiple case studies. BIM-CAREM is applied to five different AEC/FM organizations, including the exploratory case study, in Turkey. While two of them are engineering and design firms, one of them is architectural design firm and two of the companies are international constructors. One of the engineering and design firm specialized in architectural, structural and building services designs, the other specialized in structural design. Additionally, a variety of building types are included in the case studies. For example, while Company B is specialized in structural design of sports and industrial facilities, Company D is constructing hospitals. As third criteria, different frame types for buildings are selected. For example, Company B is performing structural design of steel and reinforced concrete projects. Furthermore, we included different size of organizations. Two of the constructors are listed within the top 100 of 2016 ENR Top 250 International Constructors list. This variety enabled us to generalize the findings of the case studies. Details of the exploratory case study and multiple case studies are explained in sections 3.2 and 4.2.

According to the results of the expert reviews, exploratory and multiple case studies, there are not any missing and any redundant processes in Building PRM and BIM PRM. Therefore, we concluded that Building PRM and BIM PRM include key AEC/FM processes and their definitions, for covering all the facility lifecycle stages. Defining BIM outcomes based on the identified BIM uses in the literature created a common understanding for users who already know BIM. We also clarified which BIM outcomes are achieved by performing specific process. This clarification created awareness for the users who do not have deep knowledge about BIM. We also increased the flexibility of BIM-CAREM by having Building PRM/BIM PRM as a separate component from

BIM MF. Because, users can select processes from the reference models and perform assessments by using BIM MF for the selected process. We also achieved to meet the demand of different users' specific assessment purposes. For example, assessment purpose of a user, who wants to measure the BIM capability of the design, can be identifying the BIM capability of the design. So that the user can improve BIM usage in coordination/collaboration. Based on this example, can improve the BIM usage in a specific process according to their BIM usage objectives/goals.

By considering the results of the exploratory case study and multiple case studies we identified Design in Company C; Design in Company A and B; and Design in Company E at L1, L2 and L3, respectively. We looked at Conceptual Planning in only Company B and its level is L1. Construction in Company D and Company E are found at L3. Facility Management in Company E is identified at L1. This variety showed that BIM capability levels and associated BIM attributes are neither insufficient nor overlapped for identifying BIM capabilities. We concluded that BIM capability levels and BIM attributes of BIM-CAREM are complete and they are suitable for assessing BIM capability of different AEC/FM organizations' processes. Furthermore, interviewees of multiple case studies indicated that BIM-CAREM is useful and helpful for creating awareness of BIM usage. BIM capability assessments through BIM-CAREM help users to understand their requirements for implementing BIM in their processes.

In conclusion, BIM-CAREM is a comprehensive and structured solution since it is developed in conformance to ISO/IEC 33000. While Building PRM and BIM PRM define each AEC/FM process, BIM MF includes the measures to be used for conducting BIM capability assessments of these processes. Compared to the other models in the literature BIM-CAREM provides a holistic BIM capability assessment approach by not focusing only the projects or the organizations for the assessment. Moreover, we covered the BIM uses in the literature while developing the BIM outcomes in BIM PRM and BIM capability levels and associated BIM attributes in BIM MF. We also enabled combination of quantitative and qualitative approaches in BIM-CAREM by having common rating scale and direct observations. BIM-CAREM also has benchmarking support.

5.2 Contributions

Our contributions can be clustered into two categories which are practical and theoretical contributions. We contributed to the literature by creating a BIM capability assessment model namely BIM-CAREM for assessing AEC/FM processes which is developed based on an established standard, namely ISO/IECC 33000. This model includes two process reference models for AEC/FM domain namely Building PRM and BIM PRM. Building PRM include key AEC/FM processes for covering all facility life cycle stages and has definitions of each process in terms of process purpose and process outcomes. BIM PRM includes the BIM related processes and has definitions of BIM related processes in terms of BIM outcomes. As the second part of the model, a BIM Measurement Framework which enables BIM capability assessments of AEC/FM processes is developed. BIM MF includes BIM capability levels, associated BIM attributes and a rating scale to be used for assessing BIM capability of selected AEC/FM processes. BIM capability levels and associated BIM attributes are created based on the BIM uses which are identified from literature and frequent key words of these BIM uses.

Practitioners can use BIM-CAREM to carry out BIM capability assessments for measuring BIM capability of a specific AEC/FM process. They can identify BIM related problems in their processes and possible areas of improvement in their BIM implementations. Based on this, users can create BIM improvement paths for using BIM more effectively in their organizations. Since

BIM-CAREM allows users to make multiple evaluations for the same process, it also enables benchmarking. Users can compare BIM capability of the specified processes within and across the organizations. Moreover, as model allows visualizing relationships between processes, users can perform root-cause analysis for BIM implementations. They can also select sub-contractors with required BIM capability levels by assessing their capabilities with BIM-CAREM.

5.3 Limitations and Future work

There are a number of limitations which are observed during the case studies. The main limitation is that BIM-CAREM Model is created based on international standards and applied in Turkish construction industry. Since BIM is not mandatory in Turkey, we could not gather evidences for some of the BIM outcomes. For example, feasibility studies are submitted to governmental organizations in which BIM outputs are not accepted. Therefore, some of the organizations do not prefer to use BIM in these kinds of practices.

Secondly, BIM-CAREM is developed focusing on general contractor's point of view rather than engineering and design firms/sub-contractors. For example, while design processes are performed more detailed in an architectural design office, design processes of general contractors are at more high level. Therefore, model requires customization in terms of organization types.

In Facility Management, processes such as asset management and space management are not defined in both of the technical reports (VTT, 1997) (PennState CIC, 1990). CIC's technical report includes only O&M related processes. Therefore, while O&M processes are explained in detail, we briefly included the asset management, space management and disaster planning and management in Building PRM and BIM PRM. These processes may need to be defined in more detail in the future.

The model does not measure the flexibility requirements of organizations. For example, most of the design offices who are working with general contractors need to accept contractors' preferences. That's because they have to be very flexible to be awarded more contracts and to maintain their existence in the market.

Model does not assess the ability of AEC/FM firms to adapt their existing processes into different construction projects in different places/countries. For example, communication between existing processes and newly adapted BIM processes are not covered explicitly.

Ownership of the BIM is not taken into account for development of "BIM Collaboration" attribute. In some cases, due to privacy models may not be shared with other stakeholders.

Also, the developed model does not have a user guideline to help users to implement it in BIM capability assessments.

Based on these limitations, we identified several tasks for future work. First of all, BIM-CAREM requires customization in terms of Turkish AEC/FM industry. Secondly, weights of BIM outcomes and BIM attribute outcomes in the existing model are taken equally. However, some

BIM outcomes and BIM attribute outcomes might not affect the overall rating equally. Therefore, identifying weights of BIM outcomes and BIM attribute outcomes might solve the limitations arise from differences between practices of general contractors and sub-contractors. Weighting can be determined based on the tags which are “Essential BIM Use” and “Enhanced BIM Use”.

Asset management, space management and disaster management processes should be defined in detail under FM.

New and more case studies should be performed to see more results for BIM-CAREM’s application in real-life. Especially, new case studies with sub-contractors are required to be carried out to evaluate applicability of the model for assessing their processes. Moreover, a tool based on BIM-CAREM can be developed to help users applying the approach easier. BIM-CAREM can be transformed into a standard as part of the ISO/IEC 33000, since it is developed based on that standard. In the long term, recording lessons learned from application of BIM-CAREM in practice might be useful for creating awareness about BIM training and for updating the curriculums of Civil Engineering Departments in universities.

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APPENDIX A – BUILDING PROCESS REFERENCE MODEL

P CONCEPTUAL PLANNING

ASSIGN PLANNING TEAM

Process ID	P1
Process name	Assign Planning Team
Process purpose	The purpose of the Assign Planning Team is to bring the planning personnel together.
Process outcomes	As a result of successful implementation of Assign Planning Team: 1. The planning services contract is issued.
Base practices	1. Assign planning team: Establish planning team. (Outcome 1)

Work Products	
1. Potential professionals	3. Planning services contract (Outcome 1)
2. Proposals	

Base Practice	Inputs	Outputs
BP1	1,2	3

STUDY/DEFINE NEEDS

Process ID	P2
Process name	Study/Define Needs
Process purpose	The purpose of the Study/Define Needs is to generate the plans for meeting user's requirements.
Process outcomes	As a result of successful implementation of Study/Define Needs: 1. User's needs are studied and determined. 2. Existing facilities are evaluated in terms of O&M costs. 3. Alternatives for providing a facility are explored.
Base practices	1. Study user requirements: Clarify user requirements. (Outcome 1) **(BIMout 1)** 2. Evaluate existing facilities: Evaluate compatibility of existing facilities with current and future operations. (Outcome 2) **(BIMout 2)** 3. Determine users' needs: Define necessary facilities. (Outcome 1) (BIMout 1) 4. Generate alternatives: Explore alternatives (e.g. buy, rent, build) for providing a facility. (Outcome 3)

Work Products	
1. Facility idea	5. Existing facilities evaluation (Outcome 2)
2. Alternate plans (Outcome 3)	6. User's need (Outcome 1)
3. User's operational plans	7. Strategic plans
4. Resources	8. User requirements (Outcome 1)

Base Practice	Inputs	Outputs
BP1	1,3,4	8
BP2	4,8	5
BP3	3,4,5,7	6
BP4	3,4,5,6,7	2

STUDY FEASIBILITY

Process ID	P3
Process name	Study Feasibility
Process purpose	The purpose of the Study Feasibility is to study Economic, Technical and Environmental Feasibilities.
Process outcomes	As a result of successful implementation of Study Feasibility: 1. Economic feasibility information is created. 2. Technical feasibility information is created. 3. Environmental project impact information is developed. 4. Feasibility study information is combined and a decision is made.
Base practices	1. Study economic feasibility: Estimate the funding requirements, perform the project cost/benefit analysis and allocate and secure project funds and their sources. (Outcome 1) **(BIMout 1)** 2. Study technical feasibility: Consider adequacy of available technology and resources to build the facility. (Outcome 2) **(BIMout 1)** 3. Study environmental feasibility: Study impact of the project on the environment. (Outcome 3) **(BIMout 1)** 4. Communicate results/decisions: Synthesize the economical, technical and environmental studies and conclude to a decision. (Outcome 4)

Work Products	
1. Resources	6. Technical feasibility information (Outcome 2)
2. Economic feasibility information (Outcome 1)	7. Feasibility study information (Outcome 4)
3. Owner's constraints	8. Codes and regulations
4. External constraints	9. Environmental project impact information (Outcome 3)
5. Alternate plans	10. Site information

Base Practice	Inputs	Outputs
BP1	1,3,4,5	2
BP2	1,2,4,5,8	6
BP3	1,2,4,5,6,8,10	9
BP4	1,2,4,6,9	7

DEVELOP PROGRAM

Process ID	P4
Process name	Develop Program

Process purpose	The purpose of the Develop Program is to define the project scope and size or capacity.
Process outcomes	As a result of successful implementation of Develop Program: 1. Owner's design objectives, constraints and criteria are collected. 2. Constraints (e.g. budget, schedule) are defined. 3. Design criteria are created. 4. Site criteria is created to select site. 5. Program is created and communicated to others.
Base practices	1. Gather information: Collect and understand all the available information that describes the facility. (Outcome 1) 2. Define scope: Define applicable constraints (e.g., budget, schedule) and the scope of the project. (Outcome 2) 3. Develop design criteria: Describe functional relationships between facility components and specify desirable facility characteristics. (Outcome 3) 4. Develop site criteria: Develop site criteria to guide site selection. (Outcome 4) 5. Communicate program: Transmit the program document and other undocumented programming information to other project functions. (Outcome 5)

Work Products	
1. Resources	8. Codes and regulations
2. Detailed user needs (Outcome 1)	9. Design criteria (Outcome 3)
3. Feasibility study information	10. Owner's constraints
4. General programming information	11. Site criteria (Outcome 4)
5. User's needs	12. Sites available
6. Scope requirements (Outcome 2)	13. Shared program (Outcome 5)
7. Siting requirements	14. Design contract

Base Practice	**Inputs**	**Outputs**
BP1	1,3,5,15,16	2
BP2	1,2,5,8,10	6
BP3	1,2,6,8,10	9
BP4	1,6,8,9,12	11
BP5	1,2,4,14	13

DEVELOP PROJECT EXECUTION PLAN

Process ID	P5
Process name	Develop Project Execution Plan
Process purpose	The purpose of the Develop Project Execution Plan, which is also called the project master plan, is to define owner's approach to project delivery options and strategy for acquisition of services.
Process outcomes	As a result of successful implementation of Develop Project Execution Plan: 1. Service requirements and project delivery options are identified. 2. Market conditions are studied. 3. Project Execution Plan (PEP) is created. 4. Contracting plan is developed. 5. PEP is shared with stakeholders.

Base practices	1. Identify required services: Identify project delivery options and necessary services such as planning, design, construction, construction management and operations and maintenance. (Outcome 1) 2. Study market conditions: Study competition between service organizations, and the availability and cost of key resources. (Outcome 2) 3. Develop project plan: Develop project execution plan. (Outcome 3) **(BIMout 1,2)** 4. Develop contracting plan: Describe contract types, contracting methods and project delivery strategy. (Outcome 4) 5. Communicate PEP: Communicate applicable PEP information to other project stakeholders. (Outcome 5)

Work Products	
1. Program	6. Contracting procedures
2. Service requirements (Outcome 1)	7. Project management procedures
3. Project delivery options (Outcome 1)	8. Contracting plan (Outcome 4)
4. Construction market information (Outcome 2)	9. Published PEP (Outcome 5)
5. PEP (Outcome 3)	

Base Practice	Inputs	Outputs
BP1	1	2,3
BP2	1	4
BP3	1,4,6,7	5
BP4	1,4,5	8
BP5	5,8	9

SELECT AND ACQUIRE SITE

Process ID	P6
Process name	Select and Acquire Site
Process purpose	The purpose of the Select and Acquire Site is to defining criteria for selecting the site.
Process outcomes	As a result of successful implementation of the Select and Acquire Site: 1. Site analysis is conducted for candidate sites. 2. Site is acquired.
Base practices	1. Identify candidate sites: Identify some potential sites. (Outcome 1) 2. Evaluate /Select site: Evaluate the candidate sites using the site criteria, and rank them in order of preference. (Outcome 1) **(BIMout 1)** 3. Acquire site: Acquire the site, including negotiation with the site owner(s) directly or with the help of a real estate agent. (Outcome 2) 4. Investigate site: Investigate the properties of the site. (Outcome 2)

Work Products	
1. Resources	8. Acquisition information
2. Candidate site information (Outcome 1)	9. Site (Outcome 2)

3. Sites availability	10. Site investigation funding
4. Site criteria	11. Site information (Outcome 2)
5. Site evaluation and conditions (Outcome 1)	12. Acquisition information (Outcome 2)
6. External constraints	13. Program
7. Financial resource	

Base Practice	Inputs	Outputs
BP1	1,3,4	2
BP2	2,4,6	5
BP3	4,5,7	9,12
BP4	4,5,10,12,13	11

D DESIGN

ARCH D ARCHITECTURAL DESIGN

DRAW UP BRIEF

Process ID	ARCH D1
Process name	Draw Up Brief
Process purpose	The purpose of the Draw Up Brief is to identify client's needs in order to define space requirements.
Process outcomes	As a result of successful implementation of the Draw Up Brief: 1. Existing situation is analyzed by considering inventory of activities and existing premises. 2. Requirements are defined. 3. Alternatives for space acquisition are evaluated. 4. Architectural brief is developed.
Base practices	1. Analyze present situation: Analyze inventory of activities and existing premises. (Outcome 1) 2. Define requirements: Define dimensional requirements, location criteria, site and economical requirements and scheduling goals. (Outcome 2) 3. Determine space acquisition alternatives: Determine alternatives for location and compare them, identify cost effects on investment, maintenance, and schedule alternatives. (Outcome 3) 4. Prepare program decision: Develop architectural brief which includes development of preliminary designs, environmental analysis of effects, risk, sensitivity and trend analyses and requirements for building permit. (Outcome 4)

Work Products	
1. Existing premises	11. Scheduling goals (Outcome 2)
2. Need of client	12. Layout drawing
3. Analysis of present situation (Outcome 1)	13. Space acquisition alternatives and comparisons (Outcome 3)
4. Strategic alternatives (Outcome 2)	14. Location alternatives and comparisons (Outcome 3)
5. Possibilities to intensify use of existing premises (Outcome 2)	15. Effects of space acquisition alternatives on investment costs (Outcome 3)

6. Possibility to increase or eliminate activities (Outcome 2)	16. Cost effects on maintenance costs of space acquisition alternatives (Outcome 3)
7. Dimensional requirements (Outcome 2)	17. Cost effects of schedule alternatives (Outcome 3)
8. Location criteria (Outcome 2)	18. Condition analysis of old premises (Outcome 3)
9. Site requirements (Outcome 2)	19. ARCH brief (Outcome 4)
10. Economical requirements (Outcome 2)	

Base Practice	Inputs	Outputs
BP1	1,2	3
BP2	3	4,5,6,7,8,9,10,11
BP3	2,3,4,5,6,7,8,9,10,11,12	13,14,15,16,17,18
BP4	3,4,5,6,7,8,9,10,11,13,14,15,16,17,18	19

DRAW UP PROGRAM

Process ID	ARCH D2
Process name	Draw Up Program
Process purpose	The purpose of the Draw Up Program is to develop design instructions.
Process outcomes	As a result of successful implementation of Draw Up Program: 1. Requirements are defined. 2. Space program is developed. 3. Procedures for a building permit are conducted. 4. Schedule and mode of operation is created. 5. Cost objectives and budget are established. 6. Architectural program and decisions concerning design solutions are made.
Base practices	1. Define requirements imposed by facility management: Define complemented brief, design instructions, life cycle principle, profitability requirement, and maintenance requirement. (Outcome 1) 2. Draw up space program and requirements: Develop space program. (Outcome 2) **(BIMout 1)** 3. Clear site and building permit: Define maintenance requirements, technical constructability, juridical constructability, local plan acceptability, environmental effects. (Outcome 3) **(BIMout 2)** 4. Plan schedule and mode of operation: Develop economic trend analysis, project schedule, mode of operation. (Outcome 4) 5. Set cost objectives, clear up financing, profitability and budget: Set, activity costs, financing plan, and budget. (Outcome 5) 6. Prepare investment decision: Make decision and prepare architectural program. (Outcome 6)

Work Products	
1. ARCH brief	15. Technical constructability (Outcome 3)
2. Complemented brief (Outcome 1)	16. Juridical constructability (Outcome 3)
3. Design instructions (Outcome 1)	17. Local plan acceptability (Outcome 3)
4. Life cycle principle (Outcome 1)	18. Environmental effects (Outcome 3)
5. Profitability requirement (Outcome 1)	19. Economic trend analysis (Outcome 4)

6. Maintenance requirement (Outcome 1)	20. Project schedule (Outcome 4)
7. Complemented brief	21. Mode of operation (Outcome 4)
8. Space program (Outcome 2)	22. Cost objectives (Outcome 5)
9. Space program	23. Activity costs (Outcome 5)
10. Geotechnical analysis	24. Financing plan (Outcome 5)
11. City plan	25. Tenancy estimate (Outcome 5)
12. Ownership	26. Profitability analysis (Outcome 5)
13. Local planning	27. Budget (Outcome 5)
14. Maintenance requirements (Outcome 3)	28. ARCH program (Outcome 6)

Base Practice	Inputs	Outputs
BP1	1	2,3,4,6
BP2	1,2,3,4,5,6	8
BP3	1,10,11,12,13	14,15,16,17,18
BP4	1,6,15,16,17,18	19,20,21
BP5	1,3,4,5,6,7,9,19,20,21	22,23,24,25,26,27
BP6	2,3,4,5,6,7,8,14,15,16,17,18,19,20,21,22,23,24,25,26,27	28

MAKE GLOBAL DESIGN

Process ID	ARCH D3
Process name	Make Global Design (Schematic Design)
Process purpose	The purpose of the Make global design is to produce alternative architectural designs for site usage and decide on the best solution for building permit application.
Process outcomes	As a result of successful implementation of Make global design: 1. ARCH program and design instructions are checked. 2. Alternative design solutions are prepared and one solution is chosen by client. 3. General layout design is prepared. 4. ARCH scheme is created. 5. Compatibility of ARCH design is checked with designs of all disciplines (STR, BS, GEO schemes). 6. Code validation is performed. 7. Architectural global design is completed. 8. Building permit application is submitted.
Base practices	1. Start building design: Control design instructions and architectural program. (Outcome 1) 2. Design alternatives: Develop alternative designs for site usage, compare them based on cost and environmental analyses and select the design solution. (Outcome 2) **(BIMout 1)** 3. Propose solution: Compare and elaborate on the selected design to choose the best solution. (Outcome 3) **(BIMout 2)** 4. Design schemes: Prepare global design and submit an application for a building permit. (Outcome 4,5,6,7,8) **(BIMout 3,4,5,6,7)**

Work Products	
1. Design instructions	12. Interior schemes
2. ARCH program	13. Description of construction method (STR) (Outcome 7)

3. Decision on design solutions	14. General description (architectural and structural solutions, principles of construction methods, calculations concerning permitted building volume, area calculations, space group based comparison, comparison of cost and design objectives with requirements) (Outcome 7)
4. Global design (Outcome 7)	15. General layout drawing (Outcome 3)
5. Checked design instruction (Outcome 1)	16. Environmental effects (Outcome 2)
6. Basic design solutions (Outcome 2)	17. General design (Outcome 4)
7. Proposed solution (Outcome 3)	18. Technical systems and compatibility (Outcome 5)
8. Briefing feedback	19. Description of construction method (Outcome 7)
9. STR schemes	20. Application for building permit (Outcome 8)
10. BS schemes	21. Designs and documents (Outcome 7)
11. GEO schemes	22. Code validation (Outcome 6)

Base Practice	Inputs	Outputs
BP1	1,2	5
BP2	3,5	6,16
BP3	3,5,6	7,15
BP4	3,5,7,8,9,10,11,12	4, 13,14,17,18,19,20,21,22

MAKE DETAIL DESIGN

Process ID	ARCH D4
Process name	Make Detail Design (Detail Design & Construction Documents)
Process purpose	The purpose of the Make Detail Design is to create detail designs for tendering.
Process outcomes	As a result of successful implementation of Make Detail Design: 6. Global design is reviewed. 7. Detailed ARCH design is developed. 8. Coordination is conducted with all design disciplines. 9. Tenders are created. 10. Detail designs for construction are prepared.
Base practices	6. Evaluate global design: Evaluate global design solutions. (Outcome 1) **(BIMout 1)** 7. Make detail designs: Design architectural detailed design such as facades, spaces, basements, and roof structures. (Outcome 2) (**BIMout 2)** 8. Check compatibility of detail designs: Check coordination with all disciplines. (Outcome 3) **(BIMout 3)** 9. Do additional tasks: Create invitations to tender. (Outcome 4) **(BIMout 5,6,9)** 10. Architectural detail design for construction: Create architectural detail design for construction. (Outcome 5) **(BIMout 4,7,8)**

Work Products	
7. Global design	12. Review of global design (Outcome 1)
8. ARCH detailed design (Outcome 2)	13. BS designs
9. Construction specification (Outcome 2)	14. STR designs
10. Description of design compatibility (Outcome 3)	15. Complementary designs for construction (Outcome 4)
11. Component suppliers designs	16. Invitations to tender (Outcome 4)
12. ARCH designs for construction (Outcome 5)	

Base Practice	Inputs	Outputs
BP1	1	7
BP2	1,8,9	2,3
BP3	2,8,9	4
BP4	2,5	10,11
BP5	2,4	6

ARCH D5 DO DESIGN TASK DURING CONSTRUCTION

Process ID	ARCH D5
Process name	Do Design Tasks During Construction
Process purpose	The purpose of the Do Design Task During Construction is to update the main architectural elements of the design to create As-Built model.
Process outcomes	As a result of successful implementation of Do Design Task During Construction: 1. As-Built model is created for use in facility management.
Base practices	1. Create As-Built design: Update architectural design based on site data for creating As-Built design. (Outcome 1) **(BIMout 1)**

BIM Work Products	
1. As- Built design (Outcome 1)	2. Architectural design

Base Practice	Inputs	Outputs
BP1	2	1

STR D STRUCTURAL DESIGN

DRAW UP BRIEF (This task usually not included in the structural engineer's design tasks)

Process ID	STR D1
Process name	Draw Up Brief
Process purpose	The purpose of the Draw Up Brief is to define structural requirements by conducting structural analyses of space acquisition alternatives.
Process outcomes	As a result of successful implementation of Draw Up Brief: 1. Structural draw up brief is created.
Base practices	1. Analyze alternatives for solving space needs: Conduct structural analysis for space alternatives. (Outcome 1)

	2. Estimate new building costs: Do cost estimations for new building. (Outcome 1)

Work Products	
1. Structural alternatives for space need (Outcome 1)	3. Structural brief including cost estimations (Outcome 1)
2. Structural needs	

Base Practice	Inputs	Outputs
BP1	2	1
BP3	2	3

DRAW UP PROGRAM (This task is not usually included in the structural designer's tasks)

Process ID	STR D2
Process name	Draw Up Program
Process purpose	The purpose of the Draw Up Program is to develop structural program based on technical requirements and structural brief.
Process outcomes	As a result of successful implementation of Draw Up Program: 1. Structural draw up program is developed.
Base practices	1. Define structural objectives: Identify technical requirements. (Outcome 1) 2. Take part in defining quality and cost objectives: Define quality and cost requirements. (Outcome 1) 3. Estimate in-service objective: Define in-service goal. (Outcome 1) 4. Estimate constructability of site: Evaluate site constructability. (Outcome 1) 5. Assist in selecting mode of operation: Help to select mode of operation. (Outcome 1)

Work Products	
1. Structural objectives (Outcome 1)	5. In-service goal (Outcome 1)
2. Structural brief	6. Constructability of site (Outcome 1)
3. Cost objectives (Outcome 1)	7. Structural program (Outcome 1)
4. Quality objectives (Outcome 1)	8. Assistance for selection of mode of operation (Outcome 1)

Base Practice	Inputs	Outputs
BP1	2	1
BP2	1,2	3,4
BP3	2,3,4	5
BP4	2,5	6
BP5	1,2,6	8,7

MAKE GLOBAL DESIGN

Process ID	STR D3
Process name	Make Global Design (Schematic Design)
Process purpose	The purpose of the Make Global Design is to design alternative solutions in order to produce sufficient design for a building permit.

Process outcomes	As a result of successful implementation of Make Global Design: 1. STR program is reviewed to start global design. 2. Structural possibilities for design are determined. 3. Alternative structural design solutions are created. 4. Compatibility of BS designs and bearing structures are checked. 5. Proposed designs of all disciplines (ARCH, BS, GEO) are compared with proposed STR designs. 6. One STR design solution is proposed. 7. Descriptions for STR design are provided. 8. Clash detection with all schemes (ARCH, BS, GOE) are conducted. 9. Global design is completed for a building permit.
Base practices	1. Start building design: Check design instructions. (Outcome 1) 2. Design alternatives: Define substructures and location on site, structural possibilities, and Loads, fire classes, material alternatives; study feasibility and durability of architectural alternatives; and define structural needs for further design. (Outcome 2) 3. Propose solution: Design structural alternatives, compare with designs of all design disciplines (BS, ARCH, GEO) and propose one STR solution. (Outcome 3,4,5,6) **(BIMout 1,2)** 4. Design Scheme: Provide descriptions for substructures and structures, conduct clash detection with all disciplines (ARCH, BS, GEO) and create global design. (Outcome 7,8,9) **(BIMout 3,4)**

Work Products	
1. Design instructions	16. External structures (Outcome 7)
2. Checked design instructions (Outcome 1)	17. In-service description of building parts (Outcome 8)
3. STR program	18. Proposed STR solution (Outcome 6)
4. Basic design solutions (ARCH)	19. Description of construction method (Outcome 9)
5. Feasibility and durability of architectural alternatives (Outcome 2)	20. Global design (Outcome 9)
6. Preliminary geotechnical analyses (GEO)	21. Compatibility of BS designs and bearing structures (Outcome 4)
7. Recommendation for further design (Outcome 2)	22. Proposed BS design solution
8. Description of construction method (ARCH)	23. Proposed ARCH design solution
9. Structural frame alternatives (position, type and main dimensions of frame, stability, foundation, structural types) (Outcome 3)	24. Proposed GEO design solution
10. Comparisons of proposed designs from all disciplines (ARCH, BS, GEO) (foundation, applicability to production, modifiability, extendibility, effects of BS installations, in-service life, physical properties, costs) (Outcome 5)	25. Proposed interior design solution
11. Comparison of all design schemes (ARCH, STR, BS) (Outcome 8)	26. Position, type and dimension of frame structures; fire protection principles for frame structures; substructure and base floor solutions, essential structural

	joints; structural solutions for acoustic, thermal water and moisture insulation; loads; environmental class; stability analysis; dimensions of main structural components; u-values. (Outcome 7)
12. Maintenance plan (Outcome 7)	27. ARCH schemes
13. Definitions for design and build (Outcome 7)	28. BS schemes
14. Quantities of building parts (Outcome 8)	29. GEO schemes
15. 3D pictures (Outcome 7)	30. Interior schemes

Base Practice	**Inputs**	**Outputs**
BP1	1,3	2
BP2	2,4,6	5,7
BP3	5,7,19,22,23,24,25	9,10,18,21
BP4	18,27,28,29,30,8	11, 12, 13,14,15,16,17,26, 19,20

MAKE DETAIL DESIGN

Process ID	STR D4
Process name	Make Detail Design (Detail Design & Construction Documents)
Process purpose	The purpose of the Make Detail Design is to develop structural detailed design for construction and tenders.
Process outcomes	As a result of successful implementation of Make Detail Design: 1. Detailed designs are created based on structural calculations. 2. Complementary designs are created for tender. 3. Detailed STR designs are created for construction.
Base practices	1. Make detail designs: Prepare output plan which includes drawing schedule and method, documents and description; and do detail designs. (Outcome 1) **(BIMout 1)** 2. Do additional tasks: Create data for invitation to tender. (Outcome 2) **(BIMout 3,4)** 3. Design for construction: Develop structural designs for construction. (Outcome 3) **(BIMout 1,2)**

Work Products	
1. Global design	9. Dimensions of structural components (dimensioning methods, standards, calculations)
2. Detailed STR designs (Foundations and frame structures, external wall and roof structures, complementary structures) (Outcome 1)	10. Dimensions of essential joints
3. Mode of operation	11. Fire technical dimensioning (fire classes, fire-technical calculations)
4. Positions of BS installations, voids and loads	12. Proposed change to designs

5. Geotechnical information	13. Detailed STR Designs for construction (Outcome 3)
6. Complementary designs for tender (Outcome 2)	14. Chosen products of contractors
7. Work specification (Outcome 1)	15. Work methods of contractors
8. Stability calculations (frame stiffening principle, calculation method, calculation output)	16. ARCH designs for production

Base Practice	Inputs	Outputs
BP1	1,3,4,5,6,8,9,10,11	2,7
BP2	2,12	6
BP3	2,4,6,12,8,14,15,16	13

STR D5 DO DESIGN TASKS DURING CONSTRUCTION

Process ID	STR D5
Process name	Do Design Tasks During Construction
Process purpose	The purpose of the Do Design Tasks During Construction is to update the main structural elements of the design to create As-Built design.
Process outcomes	As a result of successful implementation of Do Design Tasks During Construction: 1. As-Built design is created for use in facility management
Base practices	1. Create As-Built design: Update structural design based on site data to create As-Built design. (Outcome 1) **(BIMout 1)**

BIM Work Products	
1. As- Built design (Outcome 1)	2. Structural design

Base Practice	Inputs	Outputs
BP1	2	1

BS D BUILDING SERVICES DESIGN

DRAW UP BRIEF

Process ID	BS D1
Process name	Draw Up Brief
Process purpose	The purpose of the Draw Up Brief is to define requirements concerning building services.
Process outcomes	As a result of successful implementation of Draw Up Brief: 1. BS brief, which includes BS design objectives, needs and space acquisition alternatives, is developed.
Base practices	1. Specify design objectives: Define BS design objectives. (Outcome 1) 2. Determine space acquisition alternatives: Identify alternatives for space acquisition from BS point of view. (Outcome 1) 3. Prepare program decision: Create BS brief which includes BS design objectives, needs and space acquisition alternatives. (Outcome 1)

Work Products	
1. Building services needs	3. BS brief (Outcome 1)
2. BS design objectives (Outcome 1)	4. Alternatives for space acquisition from BS point of view (Outcome 1)

Base Practice	Inputs	Outputs
BP1	1	2
BP2	1,2	4
BP3	1,2,4	3

DRAW UP PROGRAM

Process ID	BS D2
Process name	Draw Up Program
Process purpose	The purpose of the Draw Up Program is to create BS program for design process.
Process outcomes	As a result of successful implementation of Draw Up Program: 1. BS alternatives are demonstrated. 2. Technical layout drawing, BS constructability and environmental effects on BS are defined. 3. Schedule and mode of operation is created. 4. BS design objectives are defined and objectives of all disciplines are integrated. 5. BS program is developed.
Base practices	1. Demonstrate BS alternatives: Check and complement input and compare and demonstrate BS alternatives. (Outcome 1) 2. Analyze BS constructability considering site conditions: Define technical layout drawing, BS constructability and environmental effects on BS (Outcome 2) 3. Define schedule and mode of operation: Comment on schedule and mode of operation. (Outcome 3) 4. Specify BS design objectives: Define BS quality level, BS design alternatives, space needs, points concerning positioning of spaces, structural safety objectives, structural disturbance protection objectives, drift material consumptions, investment costs, maintenance costs. (Outcome 4) 5. Compare and integrate objectives of all disciplines (Outcome 4) 6. Get acceptance for program: Create BS program and get approval. (Outcome 5)

Work Products	
1. Space program (ARCH)	9. Integrated objectives (Outcome 5)
2. BS brief	10. Environmental effects on BS (Outcome 2)
3. BS design objectives (BS quality objectives, BS design alternatives, space needs, points concerning positioning of spaces, structural safety objectives, structural disturbance protection objectives, drift material	11. Schedule proposal

consumptions, investment costs, maintenance costs) (Outcome 4)	
4. BS alternatives (Outcome 1)	12. Proposal on mode of operation
5. Connections to external networks and systems	13. Comments on mode of operation (Outcome 3)
6. Technical layout drawing (Outcome 2)	14. Comments on schedule (Outcome 3)
7. Easement and servitudes on site	15. BS program (Outcome 6)
8. BS constructability (Outcome 2)	

Base Practice	Inputs	Outputs
BP1	2	4
BP2	4,5,7	6,8,10
BP3	6,8,10,11,12	13,14
BP4	1	3
BP5	3	9
BP6	6,8,10, 13,14,3,9	15

MAKE GLOBAL DESIGN

Process ID	BS D3
Process name	Make Global Design (Schematic Design)
Process purpose	The purpose of the Make Global Design is to create BS design by comparing designs from all disciplines.
Process outcomes	As a result of successful implementation of Make Global Design: 1. BS program is reviewed. 2. BS design solutions are proposed based on site usage and masses. 3. Proposed BS design solutions and their costs are compared against proposed design solutions of all disciplines (ARCH, STR, GEO). 4. BS design solutions (HVAC, AUT, TEL, ELE) are compared and integrated. 5. BS scheme designs (HVAC, AUT, TEL, ELE) are created. Each BS scheme is composed of following elements. HVAC scheme designs: • service areas • design HVAC-systems • energy measurements • heating and cooling capacities AUT scheme designs: • structure of system • extension and functions of system • sub distribution equipment TEL scheme designs: • design functions of systems • field experiments • design usage of special rooms • encoding of safety data and distribution • disturbance and protection principles ELE scheme designs: • space (room) and isolation classes • lighting solutions

	• grouping areas • capacity, compensation and filtering requirements • secured and undisturbed usage • energy measurements • control systems and requirements • disturbance and protection principles 6. BS schemes (HVAC, AUT, TEL, ELE) are coordinated with scheme designs of all disciplines (ARCH, STR, GEO) and cost and maintenance objectives are checked. 7. BS global designs are approved.
Base practices	1. Start global design: Review BS program. (Outcome 1) 2. Make BS proposed solutions: Compare site usage and masses regarding to BS and make BS proposed solutions. (Outcome 2) **(BIMout 1)** 3. Compare BS design solutions: Compare proposed BS design solutions with proposed design solutions of all disciplines (ARCH, STR, GEO) and check costs and maintenance objectives of BS design solutions. (Outcome 3) **(BIMout 2)** 4. Choose BS design solutions: Compare and integrate all BS design solutions (HVAC, AUT, TEL, ELE), and choose and get approvals for BS design solutions. (Outcome 4) **(BIMout 3)** 5. Make scheme design: Create BS scheme designs for all disciplines (HVAC, AUT, TEL, ELE). (Outcome 5) **(BIMout 4)** 6. Integrate BS global designs: : Conduct clash detection between BS schemes (HVAC, AUT, TEL, ELE) and schemes of all design disciplines (ARCH, STR, GEO) and check cost and maintenance objectives and get approvals for global designs (Outcome 6,7) **(BIMout 4)**

Work Products	
1. Comments on BS program (Outcome 1)	12. ARCH scheme
2. BS program	13. Feasible BS design solutions (Outcome 4)
3. Proposed BS design solutions (Description of alternatives, integration possibilities, modification possibilities, connections to existing systems, functionality of special spaces) (Outcome 2)	14. STR scheme
4. Basic alternatives (ARCH)	15. Comparisons of all BS design solutions(HVAC, AUT, TEL, ELE) (Outcome 4)
5. ARCH Preliminary layout drawing	16. GEO scheme
6. BS global designs (Outcome 7)	17. HVAC schemes (Outcome 5)
7. Proposed STR design solution	18. ELE schemes (Outcome 5)
8. Proposed ARCH design solution	19. AUT schemes (Outcome 5)
9. Proposed GEO design solution	20. TEL schemes (Outcome 5)
10. Comparisons of proposed BS design solutions with proposed design solutions of all disciplines (ARCH, STR,GEO) (Outcome 3)	21. Clash detection with schemes of all design disciplines (ARCH,STR,GEO) (Outcome 6)

11. BS cost comparisons (investment costs, maintenance costs, energy consumption, reciprocal cost effects) (Outcome 3)	

Base Practice	Inputs	Outputs
BP1	2	1
BP2	1,4,5	3
BP3	3, 7,8, 9	10,11
BP4	7,15	14,15
BP5	20,21,	17,18,19,20
BP6	17,18,19,20,12,14,16	6,21

MAKE DETAIL DESIGN

Process ID	BS D4
Process name	Make Detail Design (Detail Design & Construction Documents)
Process purpose	The purpose of the Make Detail Design is to produce detailed BS design for tender and construction.
Process outcomes	As a result of successful implementation of Make Detail Design: 1. Required information for construction and facility management are specified. 2. Detailed BS designs (HVAC, AUT, TEL, ELE) are created. Detailed HVAC design: • calculation of heating and cooling need of rooms • define and design room equipment • pipelines, control, adjustment • define and design main distribution equipment Detailed AUT design: • process control, methods, usage principles • adjustment functions • electrical and program interlocking • monitoring and control systems • software requirements • requirements on control, distribution, and field equipment • remote connections, reporting requirements • user interfaces Detailed TEL design: • specify point-positions • damping calculation, circuit values • wire-routings • check external disturbance and protection • protection against sabotage • distribution central, switch cabinets Detailed ELE design: • Lighting-fixture specification • Wire-routings • Distribution systems and switchboards • Service areas • Control systems and solutions

	• Final electrical point-position 3. Coordination is conducted for all detailed BS designs (HVAC, AUT, TEL, ELE). 4. Detailed BS designs are approved.
Base practices	1. Specify input data: Specify required information related to construction and facility management. (Outcome 1) 2. Prepare detailed BS designs: Create detailed BS designs (HVAC, AUT, TEL, ELE). (Outcome 2) **(BIMout 1)** 3. Integrate detailed BS designs: Compare and integrate detailed BS designs (HVAC, AUT, TEL, ELE). (Outcome 3) **(BIMout 2)** 4. Get approvals for detailed design: Decide on detailed BS designs. (Outcome 4) **(BIMout 3,4,5)**

Work Products	
1. Global designs	7. ARCH layout drawing
2. Decision on scheme designs	8. Coordination results of detailed BS designs (Outcome 3)
3. Needs for construction and facility management (Outcome 1)	9. Comparison results for detailed BS designs (Outcome 3)
4. BS general design (Outcome 2)	10. Detailed BS designs (Outcome 4)
5. Detailed HVAC design (Outcome 2)	11. Detailed TEL design (Outcome 2)
6. Detailed AUT design (Outcome 2)	12. Detailed ELE design (Outcome 2)

Base Practice	**Inputs**	**Outputs**
BP1	1,2	3
BP2	1,3,7	4,5,6,11,12
BP3	4,5,6,11,12	8,9
BP4	4,8,9	10

BS D5 DO DESIGN TASKS DURING CONSTRUCTION

Process ID	BS D5
Process name	Do Design Tasks During Construction
Process purpose	The purpose of the Do Design Tasks During Construction is to update the main building services elements of the design to create As-Built design.
Process outcomes	As a result of successful implementation of Do Design Tasks During Construction: 1. As-Built design is created for use in facility management.
Base practices	1. Create As-Built design: Update BS design based on site data for creating As-Built design. (Outcome 1) (BIMout 1)

BIM Work Products	
1. As- Built design (Outcome 1)	2. Building services design

Base Practice	**Inputs**	**Outputs**
BP1	2	1

GEO D GEOTECHNICAL DESIGN

DRAW UP BRIEF (Briefing is not usually included in the geotechnical design tasks.)

Process ID	GEO D1
Process name	Draw Up Brief
Process purpose	The purpose of the Draw Up Brief is to determine design requirements from geotechnical point of view.
Process outcomes	There are no available process outcomes.
Base practices	There are no available base practices.

Work Products
There are no available work products.

DRAW UP PROGRAM

Process ID	GEO D2
Process name	Draw up program
Process purpose	The purpose of the Draw Up Program is to define geotechnical program.
Process outcomes	As a result of successful implementation of Draw Up Program: 1. Geotechnical requirements are identified and design objectives are set. 2. Geotechnical program is created.
Base practices	1. Define design objectives: Define geotechnical quality objectives. (Outcome 1) 2. Assemble geotechnical information: Gather environment, measurement, soil data. (Outcome 1) 3. Define subsoil exploration and measuring program: Define subsoil exploration and measurement program. (Outcome 2) 4. Compare alternative sites: Compare sites based on environmental effects of foundation construction. (Outcome 2) 5. Define geotechnical requirements of chosen site: Carry out foundation engineering measures and costs. (Outcome 2)

Work Products	
1. GEO brief	6. Description of solutions (Outcome 2)
2. Geotechnical quality objectives (Outcome 2)	7. Alternatives sites
3. Geotechnical information	8. Comparison of alternatives (Outcome 2)
4. Existing geotechnical information on alternative sites (Outcome 2)	9. Environmental effects of foundation construction
5. Subsoil exploration and measurement program (Outcome 2)	10. GEO program (Outcome 2)

Base Practice	**Inputs**	**Outputs**
BP1	1	2
BP2	1,2,3,7	4
BP3	1,2,4	5
BP4	1,2,4,5,7	6,8,9

BP5	1,2,6,8,9	10

MAKE GLOBAL DESIGN

Process ID	GEO D3
Process name	Make Global Design (Schematic Design)
Process purpose	The purpose of the Make Global Design is to develop alternative geotechnical designs and scheme.
Process outcomes	As a result of successful implementation of Make Global Design: 1. GEO program is reviewed. 2. Existing geotechnical information is gathered and alternative GEO designs are created. 3. A decision is made and a design solution is proposed. 4. GEO global design is prepared.
Base practices	1. Start building design: Review GEO program and design instructions. (Outcome 1) 2. Design alternatives: Gather existing geotechnical information and alternative GEO designs are created. (Outcome 2) **(BIMout 1)** 3. Propose solution: Propose GEO design. (Outcome 3) (BIMout 1) 4. Design schemes: Create GEO global design including description of foundation method. (Outcome 4) **(BIMout 2)**

Work Products	
1. Design instructions	8. GEO design solution (Foundation, underground spaces, excavations, drainage, subsoil structures, foundation of yard, drainage of yard, underdrains, structures of yard) (Outcome 3)
2. Checked design instruction (Outcome 1)	9. ARCH preliminary design
3. GEO program	10. Proposed ARCH design solution
4. Experiment, laboratory and measurement program (Outcome 2)	11. GEO global designs (Outcome 4)
5. Analyzed experiments and measurements (Outcome 2)	12. Description of foundation method (Outcome 4)
6. Foundation methods and limits (Outcome 2)	13. Positioning on site (Outcome 2)
7. Alternative GEO designs (Outcome 2)	

Base Practice	**Inputs**	**Outputs**
BP1	1,3	2
BP2	2	4,5,6,7,13
BP3	2,4,5,6,10	8
BP4	2,9	11, 12

MAKE DETAIL DESIGN

Process ID	GEO D4
Process name	Make Detail Design (Detail Design & Construction Documents)
Process purpose	The purpose of the Make Detail Design is to develop GEO detail design.

Process outcomes	As a result of successful implementation of Make Detail Design: 1. Detailed GEO designs are created. 2. Detailed GEO designs are developed for construction.
Base practices	1. Design details: Design detailed GEO designs. (Outcome 1) **(BIMout 1)** 2. Design for construction: Create GEO designs for construction. (Outcome 2) **(BIMout 2,3)**

Work Products	
1. GEO global designs	3. Detailed GEO design for construction (Outcome 2)
2. Detailed GEO designs (Output and documentation plan, analyzed experiments and measurements, designs for foundations of building, foundation of yard, subsoil drainage plan, plat of bottom and tubing plan, foundation structures plan, excavation and bottom stopping plan) (Outcome 1)	

Base Practice	**Inputs**	**Outputs**
BP1	1	2
BP2	2	3

GEO D5 MAKE TASKS DURING CONSTRUCTION

Process ID	GEO D5
Process name	Do Design Tasks During Construction
Process purpose	The purpose of the Do Design Tasks During Construction is to update the main geotechnical elements of the design to create As-Built design.
Process outcomes	As a result of successful implementation of Do Design Tasks During Construction: 1. As-Built design is created for use in facility management.
Base practices	1. Create As-Built design: Update geotechnical design based on site data to create As-Built design. (Outcome 1) **(BIMout 1)**

BIM Work Products	
1. As- Built design (Outcome 1)	2. BS design

Base Practice	**Inputs**	**Outputs**
BP1	2	1

C CONSTRUCTION

ACQUIRE CONSTRUCTION SERVICES

Process ID	C1
Process name	Acquire Construction Services

Process purpose	The purpose of the Acquire Construction Services is to select and organize the construction team of constructors, subcontractors, consultants, and other additional staff, by coordinating appropriate contracts and agreements.
Process outcomes	As a result of successful implementation of Acquire Construction Services: 1. Qualified parties who will be invited to bid on a work package are identified. 2. Work scope information is communicated to the qualified parties. 3. Proposals for bid are prepared by qualified parties. 4. Proposals are reviewed and a constructor is selected based on the criteria set by the staffing plan. 5. Contracts between parties are completed.
Base practices	1. Identify qualified parties: Identify qualified parties to perform aspects of the work as specified in the staffing plan. (Outcome 1) **(BIMout 1)** 2. Provide work scope information: Share work scope information with qualified parties. (Outcome 2) 3. Prepare and submit proposals: Develop bid prices and plans based on the work scope information. (Outcome 3) **(BIMout 2)** 4. Review proposals and select constructor: Check proposals against the intended work scope and select a constructor. (Outcome 4) **(BIMout 3)** 5. Execute contracts/agreements: Formalize contracts between parties. (Outcome 5) **(BIMout 4)**

Work Products	
1. Qualified parties (Outcome 1)	7. Proposals (Outcome 3)
2. Bid and construction documents and criteria	8. Requests for clarification (Outcome 4)
3. Staffing Plan	9. Selected constructor (Outcome 4)
4. Economy and resource availability	10. Project information and contract requirements (Outcome 5)
5. Work scope information (Outcome 2)	11. Contracts (Outcome 5)
6. Requirements for bid information (Outcome 3)	12. Construction Team (Outcome5)

Base Practice	**Inputs**	**Outputs**
BP1	2,3,4	1
BP2	2,3	5
BP3	4,5	6,7
BP4	2,3,7	8,9
BP5	2,3	10,11,12

PLAN AND CONTROL THE WORK

Process ID	C2
Process name	Plan and Control the Work

Process purpose	The purpose of the Plan and Control the Work is to establish the strategies for organizing the construction team, providing resources and building the facility.
Process outcomes	As a result of successful implementation of Plan and Control the Work: 1. Construction plan including work methods plans, estimates, and schedules, is formulated. 2. Budgets and aggressive schedules are developed for use by the procurement and field labor teams, submittals and shop drawings are communicated with owner and designers. 3. Work is monitored and performance reports are created for analyzing job progress. 4. The status of the work is evaluated, problems are identified and investigated, and the sources of problems are located.
Base practices	1. Develop the construction plan: Formulate the construction plan including work methods plans, estimates, and schedules. (Outcome 1) **(BIMout 1,2)** 2. Implement the plan: Convert the construction plan into execution plan, develop budgets and aggressive schedules, communicate to owner and designers in the form of submittals and shop drawings. (Outcome 2) **(BIMout 3,4)** 3. Monitor performance: Monitor the work and develop performance reports for analyzing job progress. (Outcome 3) **(BIMout 5)** 4. Analyze performance: Evaluate the status of the work, identify problems and determine required changes in the construction plan. (Outcome 3)

Work Products	
1. Facility construction knowledge (Outcome 1)	8. Historical data (Outcome 3)
2. Past facility construction knowledge	9. Performance information needs and criteria
3. Construction plan (Outcome 1)	10. Performance reports (Outcome 3)
4. Safety standards and resource availability	11. Performance information
5. Project information and control requirements	12. Performance feedback (Outcome 3)
6. Constructor submittals (Outcome 2)	13. Expected level of performance
7. Construction execution plan (Outcome 2)	14. Contract requirements

Base Practice	Inputs	Outputs
BP1	2,4,5	1,3
BP2	3	6,7
BP3	9,11	8,10
BP4	10,13,14	12

PROVIDE RESOURCES

Process ID	C3
Process name	Provide Resources
Process purpose	The purpose of the Provide Resources is to acquire and allocate the resources.
Process outcomes	As a result of successful implementation of Provide Resources: 1. Site facilities including job trailers, laydown areas, parking areas, and other site facilities, are set up. 2. Resources are acquired in accordance with the schedule and taking into account the delivery, inventory, and maintenance feedback information. 3. Quantity and quality of the acquired resources are checked and accepted. 4. Resources are stockpiled and on-hand inventory is tracked. 5. Routine preventative maintenance is performed for fixing the resource items. 6. The distribution priorities for the on-hand resources are determined based on the construction schedule, available inventory, and the need for resources.
Base practices	1. Mobilize: Set up the job trailers, laydown areas, parking areas, and other site facilities. (Outcome 1) 2. Acquire resources: Obtain the needed resources as shown in the material takeoff in accordance with the schedule and taking into account the delivery, inventory, and maintenance feedback information. (Outcome 2) **(BIMout 1,2)** 3. Receive and inspect the resources: Check acquired resources to verify that the quantity and quality of the order is correct. (Outcome 3) 4. Store the resources and manage inventory: Stockpile resources and track the on-hand inventory. (Outcome 4) **(BIMout 1)** 5. Repair and maintain the resources: Perform routine preventative maintenance to repair the resources if required. (Outcome 5) 6. Allocate the resources: Determine the distribution priorities for the on-hand resources based on the construction schedule, available inventory, and the need for resources. (Outcome 6) **(BIMout 3)**

Work Products	
1. Site and resource	13. Partially consumed resources
2. Mobilized site (Outcome 1)	14. Inventory information (Outcome 4)
3. Site layout plan	15. Storage procedures (Outcome 4)
4. Resource acquisition plan	16. On-hand resources (Outcome 4)
5. Resource acquisition information (Outcome 2)	17. Items in need of repair
6. Material take off and schedule	18. Maintenance information (Outcome 5)
7. Delivery schedule (Outcome 2)	19. Identified repair needs
8. Resource availability	20. Maintained resources (Outcome 5)
9. Acquired services (Outcome 2)	21. Maintenance program
10. Delivery information (Outcome 3)	22. Available resources (Outcome 6)
11. Accepted resources (Outcome 3)	23. Distribution priorities (Outcome 6)
12. Quality standards	24. Schedule

Base Practice	Inputs	Outputs
BP1	1,3,4	2
BP2	6,8	5,7,9
BP3	7,9,12	10,11
BP4	11,13,15	14,16,17
BP5	17,19,21	18,20
BP6	14,16,24	22,23

BUILD FACILITY

Process ID	C4
Process name	Build Facility
Process purpose	The purpose of the Build Facility is to construct the facility according to the design using available resources.
Process outcomes	As a result of successful implementation of Build Facility: 1. Daily distribution plan is created based on the construction execution plan. 2. Resources are distributed to the appropriate work areas. 3. Facility elements are constructed by consuming resources. 4. Completed work is checked regarding to quantity, quality, and location of the product and constructed facility is approved. 5. Constructed building systems are tested, permits are obtained, facility is started up and facility is handed over to the owner.
Base practices	1. Plan the daily work: Utilize instructions for conducting the daily work based on the construction execution plan. (Outcome 1) 2. Distribute the resources: Transport the needed resources to the appropriate work areas based on the daily distribution plan. (Outcome 2) 3. Do the physical work: Construct the facility elements. (Outcome 3) **(BIMout 1,2,3)** 4. Inspect and approve the work: Check the completed work to assure that the quantity, quality, and location of the product is sufficient and that the contract requirements were fulfilled and approve the constructed facility. (Outcome 4) **(BIMout 4)** 5. Turn over the completed work: Test and adjust the building systems, obtain the occupancy permit, start up the facility and submit operation information to the owner. (Outcome 5) **(BIMout 5)**

Work Products	
1. Progress information (Outcome 1)	12. Environment
2. Construction execution plan	13. Partially consumed resources (Outcome 3)
3. Daily plan (Outcome 1)	14. Completed facility elements (Outcome 3)
4. Environment and governmental requirements	15. Inspection records information (Outcome 4)
5. Field experience	16. Daily approval plan

6. Available resources and mobilized site	17. Approved work (Outcome 4)
7. Distribution progress information (Outcome 2)	18. Inspections
8. Distributed resources (Outcome 2)	19. Handover information (Outcome 5)
9. Distribution priorities	20. Startup plan
10. Work progress information (Outcome 3)	21. Post construction information (Outcome 5)
11. Daily work plan	22. Facility (Outcome 5)

Base Practice	Inputs	Outputs
BP1	2,4,5	1,3
BP2	3,6,9	7,8
BP3	8,11,12	10,13,14
BP4	14,16,18	15,17
BP5	17,20	19,21,22

FM FACILITY MANAGEMENT

Process ID	FM1
Process name	Plan/Control Facility
Process purpose	The purpose of the Plan/Control Facility is to develop plans for main FM tasks, to execute these plans, and to monitor the actual performance.
Process outcomes	As a result of successful implementation of Plan/Control Facility: 1. Facility management plan including solutions/decisions about main FM tasks such as asset, operations, space, and risk management. 2. Plans for main FM tasks are implemented. 3. Data specified in the plans such as asset data in asset register/databases are collected to control facility condition.
Base practices	1. Develop facility management plan: Develop facility management plan which includes solutions/decisions about main FM tasks such as asset, operations, space, and risk management. **(BIMout 1,2,3)** 2. Implement facility management plan: Implement management decisions. **(BIMout 1,2,3)** 3. Monitor facility: Collect data specified in the plans to control conditions such as asset condition and space utilizations. **(BIMout 1,2,3)** 4. Analyze performance of facility: Investigate performance about main FM tasks based on monitoring data. **(BIMout 1,2)**

Work Products	
1. Facility management plan (Outcome 1)	4. Performance feedback (Outcome 4)
2. Implementation information (Outcome 2)	5. Optimization information
3. Performance reports (Outcome 3)	

Base Practice	Inputs	Outputs
BP1	5	1

BP2	1	2
BP3	2	3
BP4	3	4

MANAGE OPERATIONS

Process ID	FM2
Process name	Manage Operations
Process purpose	The purpose of the Manage Operations is to provide short-term planning and management for meeting the required operating standards of the facility and for its maintenance.
Process outcomes	As a result of successful implementation of Manage Operations: 1. Physical performance information and operations historical data is reviewed. 2. Operations execution plan is created. 3. O&M services and resources are acquired.
Base practices	1. Review data: Review the operations data and historical data. (Outcome 1) **(BIMout 1)** 2. Plan operations: Plan/Re-plan and schedule operations. (Outcome 2) **(BIMout 2)** 3. Acquire operations services and resources: Acquire of all the resources and services needed by all operations and maintenance functions. (Outcome 3)

Work Products	
1. Physical performance information	6. Operations knowledge (Outcome 2,3)
2. Evaluated performance information (Outcome 1)	7. Operations resource needs (Outcome 2)
3. Operations plan	8. PEP
4. Facility operations documents	9. Available resources
5. Operations execution plan (Outcome 2)	10. Resources (Outcome 3)

Base Practice	**Inputs**	**Outputs**
BP1	1,3,4	2
BP2	2,3,4,8	5,6,7
BP3	7,8,9	6,10

MONITOR FACILITY CONDITIONS AND SYSTEMS

Process ID	FM3
Process name	Monitor Facility Conditions and Systems
Process purpose	The purpose of the Monitor Facility Conditions and Systems is to establish monitoring mechanism for facility conditions and systems.
Process outcomes	As a result of successful implementation of Monitor Facility Conditions and Systems: 1. Points/areas which would best represent the section(s) of the facility to be monitored are selected. 2. Monitoring mechanism/system is selected. 3. Data related to operations is collected.

	4. Data is stored, classified, or simplified in order to be used by other functions.
Base practices	1. Select critical points/areas to monitor: Select points/areas which would best represent the section(s) of the facility to be monitored. (Outcome 1) **(BIMout 1)** 2. Select monitoring mechanism: Select the mechanism/system which will carry out/assist in the monitoring process. (Outcome 2) 3. Collect data: Collect all the data related to the operations. (Outcome 3) 4. Transform data into information: Transform the monitoring data to information in a format which can be understood and/or further processed by all mechanisms. (Outcome 4) **(BIMout 2)**

Work Products	
1. Monitoring areas (Outcome 1)	4. Monitoring mechanism (Outcome 2)
2. Operations plan	5. Operation data (Outcome 3)
3. Physical performance information	6. Monitoring information (Outcome 4)

Base Practice	Inputs	Outputs
BP1	2	1
BP2	1,2	4
BP3	1,4,3	5
BP4	5	6

EVALUATE CONDITIONS AND DETECT PROBLEMS

Process ID	FM4
Process name	Evaluate Conditions and Detect Problems
Process purpose	The purpose of the Evaluate Conditions and Detect Problems is to detect problems and identify the source and the reason of the problem.
Process outcomes	As a result of successful implementation Evaluate Conditions and Detect Problems: 1. Monitoring information is compared with critical or expected performance values. 2. Problem location and cause is identified. 3. Problem area is notified.
Base practices	1. Evaluate information against standards: Compare information with the critical or expected performance values. (Outcome 1) **(BIMout 1)** 2. Locate and identify problems: Find out where the problem is and determine what the problem is. (Outcome 2) **(BIMout 1)** 3. Notify problem: Notify about the problem area for developing a solution. (Outcome 3)

Work Products	
1. Monitoring information	5. Operations plan
2. Problem data (Outcome 1)	6. Problem identification (Outcome 2)
3. User requirements	7. Problem area notification (Outcome 3)
4. Facility operations documents	

Base Practice	Inputs	Outputs
BP1	1,3,5	2
BP2	2,5,4	6
BP3	6	7

DEVELOP SOLUTIONS

Process ID	FM5
Process name	Develop Solutions
Process purpose	The purpose of Develop Solutions is to develop alternative solution plans for the identified problems.
Process outcomes	As a result of successful implementation of Develop Solutions: 1. A full understanding of the problem is achieved. 2. Necessary information and skills are determined and assembled. 3. Technical solution for the problem is developed. 4. Implications of the problem solving plan are analyzed. 5. Alternative problem solving plans are communicated.
Base practices	1. Understand the problem: Understand the problem area and generate the necessary information to develop solutions. (Outcome 1) **(BIMout 1)** 2. Determine necessary information and skills: Determine the information and skills needed to solve a problem. (Outcome 2) 3. Assemble necessary information and skills: Collect/put together the information and skills needed to solve a problem. (Outcome 2) 4. Develop/design solutions: Design a technical solution for the problem. (Outcome 3) **(BIMout 2)** 5. Analyze implications: Analyze the implications of the problem solving plan. (Outcome 4) **(BIMout 3)** 6. Present alternatives: Communicate the set of alternatives. (Outcome 5)

Work Products	
1. Problem area	7. External constraints
2. Problem information (Outcome 1)	8. Technical solutions (Outcome 3)
3. Facility operations documents	9. User requirements
4. Operations plan	10. Problem solution implications (Outcome 4)
5. Operations knowledge	11. Communicated alternative plans (Outcome 5)
6. Skills and information (Outcome 2)	12. Alternative problem solving plans (Outcome 5)

Base Practice	Inputs	Outputs
BP1	1,3,4	2
BP2	2,3,4,5	6
BP3	6	6
BP4	3,4,5,6	8
BP5	7,8,9	10
BP6	9,10	11,12

SELECT PLAN OF ACTION

Process ID	FM6
Process name	Select Plan of Action
Process purpose	The purpose of the Select Plan of Action is to select one of the alternative plans.
Process outcomes	As a result of successful implementation of Select Plan of Action: 1. Alternative problem solving plans and their implications are understood. 2. Consequences of the suggested alternative plans are considered to select an alternative. 3. Problem solution plan is selected including allocated services and resources.
Base practices	1. Understand alternatives and their implications: Understand the alternative problem solving plans and their implications. (Outcome 1) 2. Select alternative: Consider the direct consequences of the suggested alternative plans and select alternative(s). (Outcome 2) **(BIMout 1)** 3. Commit services and resources: Allocate the services and resources such as people, materials, equipment, contractor to implement the selected plan. (Outcome 3) **(BIMout 2)**

Work Products	
1. Alternatives	4. Selected alternative (Outcome 2)
2. Problem solving alternatives and implications (Outcome 1)	5. Problem solving plan (Outcome 3)
3. Problem feedback (Outcome 2)	

Base Practice	**Inputs**	**Outputs**
BP1	1	2
BP2	2	3,4
BP3	4	5

IMPLEMENT PLAN

Process ID	FM7
Process name	Implement Plan
Process purpose	The purpose of the Implement Plan is to execute the physical operations and maintenance function.
Process outcomes	As a result of successful implementation of Implement Plan: 1. Resources are distributed for O&M work. 2. O&M is performed. 3. Maintenance work is inspected and performance information is collected.
Base practices	1. Distribute resources: Give the resources necessary to carry out the designated operations or maintenance work. (Outcome 1) 2. Do the work: Implement the physical work. (Outcome 2) **(BIMout 1)** 3. Inspect work: lnclude the inspection of the maintenance. (Outcome)

Work Products	
1. Consumable resources	5. Facility operations documents
2. Distributed resources (Outcome 1)	6. Operational facility (Outcome 2)
3. Problem solving plan	7. Operating systems (Outcome 2)
4. Executing plan	8. Physical performance information (Outcome 3)

Base Practice	Inputs	Outputs
BP1	1,3,4,5	2
BP2	2,3,4,5	6,7
BP3	3,4,5,7	8

APPENDIX B – BIM PROCESS REFERENCE MODEL

P CONCEPTUAL PLANNING

ASSIGN PLANNING TEAM

Process ID	P1
Process name	Assign Planning Team
Process purpose	The purpose of the Assign Planning Team is to bring the planning personnel together.
BIM outcomes	There are no available BIM outcomes.

STUDY/DEFINE NEEDS

Process ID	P2
Process name	Study/Define Needs
Process purpose	The purpose of the Study/Define Needs is to generate the plans for meeting user's requirements.
BIM outcomes	As a result of successful implementation of Study/Define Needs: 1. User needs and requirements are defined regarding BIM usage in Design, Construction and FM phases. 2. Existing Conditions: Existing conditions modeling is conducted for a site/facilities on site/a specific area within a facility. (Essential BIM Use)

Work Products	
5. User needs regarding BIM (BIMout 1)	3. Point cloud data from laser scanner (BIMout 2)
6. Existing facilities evaluation (BIMout 2)	

STUDY FEASIBILITY

Process ID	P3
Process name	Study Feasibility
Process purpose	The purpose of the Study Feasibility is to study economic, technical and environmental feasibilities.
BIM outcomes	As a result of successful implementation of Study Feasibility: 1. Feasibility information (Economic, environmental and technical) is studied.

Work Products	
6. Economic feasibility information (BIMout 1)	3. Environmental project impact information (BIMout 1)
2. Technical feasibility information (BIMout 1)	

DEVELOP PROGRAM

Process ID	P4
Process name	Develop Program
Process purpose	The purpose of the Develop Program is to define the project scope and size or capacity.
BIM outcomes	There are no available BIM outcomes.

DEVELOP PROJECT EXECUTION PLAN/ BIM EXECUTION PLAN

Process ID	P5
Process name	Develop BIM Execution Plan
Process purpose	The purpose of the Develop BIM Execution Plan (BEP) is to defined BIM as part of project delivery strategy, identify required BIM services, project goals related to BIM and prepare BIM Execution Plan (BEP).
BIM outcomes	As a result of successful implementation of Develop BIM Execution Plan: 1. Define BIM as part of project delivery strategy and identify required BIM services. 2. BEP is created.

BIM Work Products	
6. BIM specification/contract (BIMout 1)	8. Quality control (BIMout 2)
7. BIM goals/BIM uses (BIMout 2)	9. Technological infrastructure needs (BIMout 2)
8. BIM roles and responsibilities /BIM staffing (BIMout 2)	10. Model Structure (BIMout 2)
9. BIM process design (BIMout 2)	11. Project deliverables (BIMout 2)
10. BIM information exchanges (BIMout 2)	12. Deliver strategy (BIMout 2)
11. BIM and facility data requirements (BIMout 2)	13. BEP (BIMout 2)
12. Collaboration procedures (BIMout 2)	

SELECT AND ACQUIRE SITE

Process ID	P6
Process name	Select and Acquire Site
Process purpose	The purpose of the Select and Acquire Site is to defining criteria for selecting the site.
BIM outcomes	As a result of successful implementation of Select and Acquire Site: 1. Site analysis: Site analysis is conducted to determine the most optimal site location. (Enhanced BIM Use)

BIM Work Products	
1. Site analysis (BIMout 2)	

D DESIGN

ARCH D ARCHITECTURAL DESIGN

DRAW UP BRIEF

Process ID	ARCH D1
Process name	Draw Up Brief
Process purpose	The purpose of the Draw Up Brief is to identify client's needs in order to define space requirements.
BIM outcomes	There are no available BIM outcomes.

DRAW UP PROGRAM

Process ID	ARCH D2
Process name	Draw Up Program
Process purpose	The purpose of the Draw Up Program is to develop design instructions.
BIM outcomes	As a result of successful implementation of Draw Up Program: 1. Draw up space program and requirements are developed (areas, volumes and etc.). 2. Programming: Design performance is assessed in terms of spatial requirements.

BIM Work Products	
1. Space program (BIMout1)	2. Assessment of design performance (BIMout2)

MAKE GLOBAL DESIGN

Process ID	ARCH D3
Process name	Make Global Design (Schematic Design)
Process purpose	The purpose of the Make Global Design is to produce architectural design for site usage and decide on the best solution for building permit application.
BIM outcomes	As a result of successful implementation of Make Global Design: 1. Design authoring: Architectural design alternatives are created. (Essential BIM Use) 2. Design authoring: General layout design is developed. (Essential BIM Use) 3. Design authoring: ARCH scheme is created. (Essential BIM Use) 4. Coordination: 3D coordination is conducted between architectural model and models from all disciplines (STR, BS, and GEO, etc.). (Essential BIM Use) 5. Code and compliance checking is performed. (Enhanced BIM Use) 6. Design authoring: ARCH global model is completed. (Essential BIM Use) 7. An application for a building permit is submitted.

BIM Work Products	
1. ARCH layout design (BIMout 1)	5. ARCH global model (BIMout 6)
2. ARCH design alternatives (BIMout 1)	6. Code validation (BIMout 5)

3. ARCH scheme (BIMout 3)	7. Application for a building permit (BIMout 7)
4. Clash detection results of models from all disciplines (ARCH, STR, BS, GEO) (BIMout 4)	

MAKE DETAIL DESIGN

Process ID	ARCH D4
Process name	Make Detail Design (Detail Design & Construction Documents)
Process purpose	The purpose of the Make Detail Design is to develop the model in detail for production and tenders.
BIM outcomes	As a result of successful implementation of Make Detail Design: 10. Design review: Design review is conducted for ARCH global model. (Essential BIM Use) 11. Design authoring: Detailed architectural model is authored. (Essential BIM Use) 12. Coordination: 3D coordination is conducted between detailed architectural model and all other detailed models (STR, BS, GEO). (Essential BIM Use) 13. Design authoring: Architectural detail model is updated further for construction. (Essential BIM Use) 14. Cost estimating: 5D cost estimating is created via quantity take off from the model. (Enhanced BIM Use) 15. Phase and 4D planning: 4D planning is prepared to plan construction sequence effectively. (Enhanced BIM Use) 16. Engineering analysis: Energy analysis is conducted based on the model to asses building energy performance. (Enhanced BIM Use) 17. Sustainability analysis: Sustainability/LEED evaluation is performed based on the model. (Enhanced BIM Use) 18. Tender documents including BIM protocols are created.

BIM Work Products	
13. Architectural detail model (BIMout 2)	6. Design review of architectural global model (BIMout 1)
14. Clash detection results of ARCH and all other models (BIMout 3)	7. Quantity take off (BIMout 5)
15. Energy and environmental analyses (BIMout 7)	8. 5D cost estimation (BIMout 5)
16. Sustainability (LEED) evaluation (BIMout 8)	9. 4D planning (BIMout 6)
17. Architectural detail model for construction (BIMout 4)	10. Tender documents for BIM usage (BIMout 9)

ARCH D5 DO DESIGN TASKS DURING CONSTRUCTION

Process ID	ARCH D5
Process name	Do Design Task During Construction
Process purpose	The purpose of the Do Design Tasks During Construction is to update the main architectural elements of the model to create the As-Built model.

BIM outcomes	As a result of successful implementation of Do Design Tasks During Construction: 2. Record modeling: As-Built model is created for use in facility management. (Essential BIM Use)

BIM Work Products	
3. As- Built Model (BIMout1)	

STR D STRUCTURAL DESIGN

DRAW UP BRIEF (This task usually not included in the structural engineer's design tasks)

Process ID	STR D1
Process name	Draw Up Brief
Process purpose	The purpose of the Draw Up Brief is to define structural requirements by conducting structural analyses of space acquisition alternatives.
BIM outcomes	There are no available BIM outcomes.

DRAW UP PROGRAM (This task is not usually included in the structural designer's tasks)

Process ID	STR D2
Process name	Draw Up Program
Process purpose	The purpose of the Draw Up Program is to develop structural program based on technical requirements and structural brief.
BIM outcomes	There are no available BIM outcomes.

MAKE GLOBAL DESIGN

Process ID	STR D3
Process name	Make Global Design (Schematic Design)
Process purpose	The purpose of the Make Global Design is to develop alternative solutions in order to produce sufficient model for a building permit.
BIM outcomes	As a result of successful implementation of Make Global Design: 1. Design authoring: Alternative structural frames are developed based on structural possibilities. (Essential BIM use) 2. Coordination: 3D coordination between BS designs and bearing structures; and 3D coordination between STR design alternatives and proposed design solutions for all disciplines (ARCH, BS, GEO) are checked and one STR solution is selected. (Essential BIM use) 3. Coordination: 3D coordination is conducted between chosen STR model and models from all disciplines (ARCH, BS and GEO). (Essential BIM use) 4. Design authoring: STR model is further authored to create structural global model. (Essential BIM use)

BIM Work Products	
16. Structural frame alternatives (BIMout 1)	4. Comparison of proposed STR design and proposed design of all disciplines (BIMout 2)

17. Compatibility of BS designs and bearing structures (BIMout 2)	5. Chosen STR solution (BIMout 2)
18. Clash detection results for schemes of all disciplines (BIMout 3)	6. Structural global model (BIMout 4)

MAKE DETAIL DESIGN

Process ID	STR D4
Process name	Make Detail Design (Detail Design & Construction Documents)
Process purpose	The purpose of the Make Detail Design is to develop structural detail model for production and tenders.
BIM outcomes	As a result of successful implementation of Make Detail Design: 1. Design authoring: Detailed STR model is created based on structural calculations. (Essential BIM use) 2. Engineering analysis: Structural analysis is conducted. (Enhanced BIM use) 3. Cost estimating: 5D cost estimation is prepared via quantity take off from model. (Enhanced BIM use) 4. Phase and 4D planning: Phase and 4D planning is developed. (Enhanced BIM use)

Work Products	
1. Detailed STR detail models (Foundations and frame structures, external wall and roof structures, complementary structures) (BIMout 1)	4. 4D planning (BIMout 4)
2. Quantity take off (BIMout 3)	5. Structural analyses (BIMout 2)
3. 5D cost estimation (BIMout 3)	

STR D5 DO DESIGN TASKS DURING CONSTRUCTION STAGE

Process ID	STR D5
Process name	Do Design Task During Construction
Process purpose	The purpose of the Do Design Task During Construction is to update the main structural elements of the model to create the As-Built model.
BIM outcomes	As a result of successful implementation of Do Design Task During Construction: 1. Record modelling: As-Built model is created for use in facility management. (Essential BIM use)

BIM Work Products	
1. As- Built Model (BIMout1)	

BS D BUILDING SERVICES DESIGN

DRAW UP BRIEF

Process ID	BS D1
Process name	Draw Up Brief
Process purpose	The purpose of the Draw Up Brief is to collect requirements concerning building services.
BIM outcomes	There are no available BIM outcomes.

DRAW UP PROGRAM

Process ID	BS D2
Process name	Draw Up Program
Process purpose	The purpose of the Draw Up Program is to create BS program for design process.
BIM outcomes	There are no available BIM outcomes.

MAKE GLOBAL DESIGN

Process ID	BS D3
Process name	Make Global Design (Schematic Design)
Process purpose	The purpose of the Make Global Design is to create BS designs.
BIM outcomes	As a result of successful implementation of Make Global Design: 1. Design authoring: Proposed BS models (HVAC, AUT, TEL, ELE) are created. (Essential BIM Use) 2. Coordination: 3D coordination is conducted between proposed BS models (HVAC, AUT, TEL, ELE) and proposed models from all disciplines (ARCH, STR, GEO). (Essential BIM Use) 3. Coordination: 3D coordination is conducted for BS models (HVAC, AUT, TEL, ELE) and BS design solutions are chosen. (Essential BIM Use) 4. Design authoring: BS schemes are created and BS global designs are approved. (Essential BIM Use)

Work Products	
1. Proposed BS models (HVAC, AUT, TEL, ELE) (BIMout 1)	5. Clash detection results of BS models (HVAC, AUT, TEL, ELE) (BIMout 3)
2. HVAC schemes (BIMout 4)	6. BS global designs (BIMout 4)
3. ELE schemes (BIMout 4)	7. AUT schemes (BIMout 4)
4. TEL schemes (BIMout 4)	8. Clash detection results between proposed BS models and proposed models of all disciplines (ARCH, STR, GEO) (BIMout 2)

MAKE DETAIL DESIGN

Process ID	BS D4
Process name	Make Detail Design (Detail Design & Construction Documents)
Process purpose	The purpose of the Make detail design is to produce building services detail model for production and tenders.

BIM outcomes	As a result of successful implementation of Make Detail Design: 1. Design authoring: Detailed BS models (HVAC, AUT, TEL, ELE) are developed. (Essential BIM Use) 2. Coordination: 3D coordination is conducted between BS detail models (HVAC, AUT, TEL, ELE). (Essential BIM Use) 3. Cost estimating: 5D cost estimation is prepared via quantity take off from model. (Enhanced BIM Use) 4. Phase and 4D planning: 4D planning is prepared. (Enhanced BIM Use) 5. Engineering analysis: Energy analyses (heating energy consumption, cooling energy consumption, electricity consumption, water consumption, lightening analysis, etc.) are carried for cost comparisons. (Enhanced BIM Use)

Work Products	
7. Quantity take off (BIMout 3)	6. Detailed AUT model (BIMout 1)
8. 5D cost estimation (BIMout 3)	7. Coordination results of detailed BS designs (BIMout 2)
9. Model requirements for use in construction and facility management (BIMout 5)	8. Detailed TEL models (BIMout 1)
10. BS general design (BIMout 1)	9. Detailed ELE models(BIMout 1)
11. Detailed HVAC model (BIMout 1)	10. 4D planning (BIMout 4)

BS D5 DO DESIGN TASKS DURING CONSTRUCTION

Process ID	BS D5
Process name	Do Design Task During Construction
Process purpose	The purpose of the Do Design Task During Construction is to update the main building services elements of the model to create the As-Built model.
BIM outcomes	As a result of successful implementation of Do Design Task During Construction: 1. Record modeling: As-Built model is created for use in facility management. (Essential BIM Use)

BIM Work Products	
1. As- Built model (BIMout1)	

GEO D GEOTECHNICAL DESIGN

DRAW UP BRIEF (Briefing is not usually included in the geotechnical design tasks.)

Process ID	GEO D1
Process name	Draw Up Brief
Process purpose	The purpose of the Draw Up Brief is to determine design requirements from geotechnical point of view.
BIM outcome	There are no available BIM outcomes.

DRAW UP PROGRAM

Process ID	GEO D2
Process name	Draw Up Program
Process purpose	The purpose of the Draw Up Program is to define geotechnical program.
BIM outcomes	There are no available BIM outcomes.

MAKE GLOBAL DESIGN

Process ID	GEO D3
Process name	Make Global Design (Schematic Design)
Process purpose	The purpose of the Make Global Design is to develop alternative geotechnical design and global geotechnical models
BIM outcomes	As a result of successful implementation of Make Global Design: 1. Design authoring: Alternative GEO designs are created and one GEO solution is selected. (Essential BIM Use) 2. Design authoring: GEO global designs are developed. (Essential BIM Use)

BIM Work Products	
1. Alternative GEO design solutions (BIMout 1)	GEO global designs (Foundation, underground spaces, excavations, drainage, subsoil structures, foundation of yard, drainage of yard, underdrains, structures of yard) (BIMout 2)

MAKE DETAIL DESIGN

Process ID	GEO D4
Process name	Make Detail Design (Detail Design& Construction Documents)
Process purpose	The purpose of the Make Detail Design is to develop geotechnical detail model.
BIM outcomes	As a result of successful implementation of Make Detail Design: 1. Design authoring: Detailed GEO model is created. (Essential BIM Use) 2. Cost estimating: 5D cost estimating is prepared from quantity take off. (Enhanced BIM Use) 3. Phase and 4D planning: 4D planning is developed. (Enhanced BIM Use)

Work Products	
1. Detailed GEO model (BIMout 1)	3. 5D cost estimation (BIMout 2)
2. Quantity take off (BIMout 2)	4. 4D planning (BIMout 3)

GEO D5 MAKE TASKS DURING CONSTRUCTION STAGE

Process ID	GEO D5
Process name	Make Tasks During Construction
Process purpose	The purpose of the Make Tasks During Construction is to update the geotechnical elements of the model to create the As-Built model.
BIM outcomes	As a result of successful implementation of Do Tasks During Construction:

	1. Record modeling: As-Built model is created for use in facility management. (Essential BIM Use)

BIM Work Products	
1. As- Built Model (BIMout1)	

C CONSTRUCTION

ACQUIRE CONSTRUCTION SERVICES

Process ID	C1
Process name	Acquire Construction Services
Process purpose	The purpose of the Acquire Construction Services is to hire the needed subcontractors, consultants, and other additional staff.
BIM outcomes	6. Qualified parties with BIM capability who will be invited to bid on a work package are identified. 7. Proposals for bid including BIM costs are prepared by qualified parties. 8. Proposals are reviewed and BIM using constructor/subcontractors are selected based on the criteria set by the staffing plan. 9. Contracts including BIM clauses are formalized.

BIM Work Products	
1. Qualified parties (BIMout 1)	3. Selected constructor (BIMout 3)
2. Proposals including BIM costs (BIMout 2)	4. Contracts (BIMout 4)

PLAN AND CONTROL THE WORK

Process ID	C2
Process name	Plan and Control the Work
Process purpose	The purpose of the Plan and Control the Work is to establish the strategies for organizing the construction team, providing resources and building the facility.
BIM outcomes	As a result of successful implementation of Plan and Control the Work: 1. Phase and 4D planning: Construction sequencing is created. (Essential BIM Use) 2. Site utilization planning: BIM is used to graphically represent facilities on site which can include labor resources, materials with associated deliveries, and equipment location. (Enhanced BIM Use) 1. 5D cost estimating is used for developing the budget. (Enhanced BIM Use) 2. Shop drawings are created using BIM. 3. Status/progress monitoring is visualized from site data. (Enhanced BIM Use)

BIM Work Products	
1. 4D plan (BIMout 1)	5. Crew locations and workforce plan (BIMout 2)
2. Site utilization plan (BIMout 2)	6. Budget (BIMout 3)
3. Materials logistics plan and equipment positioning (BIMout 2)	7. Shop drawings (BIMout 4)
4. Status/progress monitoring (BIMout 5)	8. Progress monitoring reports (BIMout 5)

PROVIDE RESOURCES

Process ID	C3
Process name	Provide Resources
Process purpose	The purpose of the Provide Resources is to acquire and allocate the resources.
BIM outcomes	As a result of successful implementation of Provide Resources: 1. Resources are acquired and inventory is managed in accordance with inventory information gathered via integrating ERP tools and BIM tools. 2. Digital fabrication: Digital fabrication is facilitated. (Enhanced BIM Use) 3. The distribution priorities are determined based on 4D plan.

BIM Work Products	
1. Inventory information (BIMout 1)	4. Fabrication of construction and materials and assemblies (sheet metal fabrication, structural steel fabrication, pipe cutting, etc.) (BIMout 2)
2. Available resources (BIMout 1)	5. Acquired resources (BIMout 1)
3. Distribution priorities (BIMout 3)	

BUILD FACILITY

Process ID	C4
Process name	Build Facility
Process purpose	The purpose of the Build Facility is to construct the facility according to the design using available resources.
BIM outcomes	As a result of successful implementation of Build Facility: 1. Daily work is executed based on 4D plan. 2. 3D location identification: Physical locations of elements on site are pinpointed for construction layout. (Enhanced BIM Use) 3. Facility is constructed by using BIM. 4. Quality assurance is conducted via BIM and site data such as pictures and point clouds. 5. Operation data is handed over to the owner with BIM.

BIM Work Products	
1. Facility (BIMout 3)	4. Locations points (BIMout 2)
2. Progress information (BIMout 1)	5. Daily work (BIMout 1)
3. Quality assurance (BIMout 4)	6. Handover information (BIMout 5)

FM FACILITY MANAGEMENT

PLAN/CONTROL FACILITY

Process ID	FM1
Process name	Plan/Control Facility
Process purpose	The purpose of the Plan/Control Facility is to develop plans for main FM tasks, to execute these plans, and to monitor the actual performance.
BIM outcome	As a result of successful implementation of Plan/Control Facility: 5. Asset management: Financial decision making, short term and long term planning and generating work orders schedules are assisted via integrating record models with asset management systems. (Enhanced BIM Use) 6. Space management: Scape distribution, management and tracking is utilized by integrating record models and spatial tracking software. (Enhanced BIM Use) 7. Disaster planning: Critical building information is made available to the responders by integrating record models and BMS which allows clear display of emergency locations. (Enhanced BIM Use)

BIM Work Products	
1. Asset/Space/Disaster management plan (BIMout 1,2,3)	3. Asset/Space/Disaster performance information (BIMout 1,2,3)
2. Asset/Space/Disaster plan implementation information (BIMout 1,2,3)	4. Asset/Space performance feedback (BIMout 1,2)

MANAGE OPERATIONS

Process ID	FM2
Process name	Manage Operations
Process purpose	The purpose of the Manage Operations is to provide short-term planning and management for meeting the required operating standards of the facility and for its maintenance.
BIM outcomes	As a result of successful implementation of Manage Operations: 1. Physical performance information and operations historical data reviewed via integrating record models and facility management systems. 2. O&M scheduling is planned by integrating record models and facility management systems such as BAS and CMMS.

BIM Work Products	
1. Evaluated performance information (BIMout 1)	2. Operations execution plan (BIMout 2)

MONITOR FACILITY CONDITIONS AND SYSTEMS

Process ID	FM3
Process name	Monitor Facility Conditions and Systems
Process purpose	The purpose of the Monitor Facility Condition and Systems is to establish monitoring mechanism for facility conditions and systems.

BIM outcomes	As a result of successful implementation of Monitor Facility Conditions and Systems: 1. Facility points/areas are selected for collecting operations data through sensors. 2. Operations data, which is collected through sensors, is stored, classified, or simplified in record model integrated with BMS in order to be used by other functions.

BIM Work Products	
1. Monitoring areas (BIMout 1)	3. Operation data (BIMout 2)
2. Monitoring information (BIMout 3)	

EVALUATE CONDITIONS AND DETECT PROBLEMS

Process ID	FM4
Process name	Evaluate Conditions and Detect Problems
Process purpose	The purpose of the Evaluate Conditions and Detect Problems is to detect problems and identify the source and the reason of the problem.
BIM outcomes	As a result of successful implementation of Evaluate Conditions and Detect Problems: 1. Monitoring information for identifying problem area is compared with critical or expected performance values which are attached to models.

BIM Work Products	
5. Problem data (BIMout 1)	6. Root-cause of the problem (BIMout 2)

DEVELOP SOLUTIONS

Process ID	FM5
Process name	Develop Solutions
Process purpose	The purpose of Develop Solutions is to develop alternative solution plans for the identified problems.
BIM outcomes	As a result of successful implementation of Develop Solutions: 1. Root-cause analysis is performed by using the model to understand the problem. 2. Technical solution for the problem is designed by using the model. 3. Implications of problem solving plan are analyzed by using the model.

BIM Work Products	
1. Necessary O&M information and skills (BIMout 1)	2. Problem solution implications (BIMout 2)

SELECT PLAN OF ACTION

Process ID	FM6
Process name	Select Plan of Action
Process purpose	The purpose of the Select Plan of Action is to select one of the alternative plans.
BIM outcomes	As a result of successful implementation of Select Plan of Action:

	1. Decisions for selecting problem solution plan are made via integrating models and facility management tools/asset management tools. 2. Services and resources for implementing the plan are allocated by integrating models and facility management tools.

BIM Work Products	
1. Problem solving plan (BIMout 1)	

IMPLEMENT PLAN

Process ID	FM7
Process name	Implement Plan
Process purpose	The purpose of the Implement Plan is to execute the physical operations and maintenance function.
BIM outcomes	As a result of successful implementation of Implement Plan: 1. Performed O&M tasks are reflected to the model.

BIM Work Products	
1. Updated record model (BIMout 1)	

APPENDIX C – BIM MEASUREMENT FRAMEWORK

Terms and Definitions:

Building Information Modeling (BIM): BIM is the process of generating models of facility information, including 3D digital objects with parametric intelligence, and storing, sharing and integrating facility information for designing, constructing and operating facilities during the life cycle.

Building Information Model: It is the digital representation of physical and functional characteristics of a building which is referred as Model (AIA, 2008).

BIM Software: It is an application for generating and analyzing physical and functional data to support different tasks throughout the facility life cycle phases.

Level of Development (LOD): LOD describes the level of completeness to which a model element is developed (AIA, 2008). It has five levels as LOD 100, 200, 300, 400 and 500.

Level of Information (LOI): LOI is the description of non-graphical content of models are each facility life cycle stages (AIA, 2008).

Level of Model Definition (LOMD): LOMD includes both of the Level of Development and Level of Information.

BIM Execution Plan (BEP): BEP is the plan in which project partners agree on how to collaborate in a BIM-supported project.

BIM Capability Level: A BIM capability level indicates an organization's BIM leverage capability in their building processes and is characterized by BIM attributes.

BIM Attribute: A BIM attribute is an observable phenomenon to be measured for identifying BIM capability level of a construction organization’s process in formal BIM capability assessments.

BIM Attribute Outcome: A BIM attribute outcome is the observable result of a BIM attribute achievement.

BIM Capability Levels and BIM Attributes:

BIM capability is defined on a four-point ordinal scale as given in Table 1.

Table 1: BIM Capability Levels and BIM Attributes

BIM Capability Level	**BIM Attributes**
LEVEL 0 - INCOMPLETE	Not Available
LEVEL 1 - PERFORMED	BIM A1.1 Performing BIM BIM A1.2 BIM Skills
LEVEL 2 - INTEGRATED	BIM A2.1 BIM Collaboration BIM A2.2 Interoperability

LEVEL 3 - OPTIMIZED	BIM A3.1 Corporate-wide BIM Deployment BIM A3.2 Continuous BIM Improvement

LEVEL 0-INCOMPLETE: The BIM is not implemented or it is partially implemented and fails to achieve the BIM outcomes.

At this level, some examples of the generic BIM work products showing that the BIM is not fully implemented are as follows:

- ✓ Designs that are composed of multiple 2D CAD reference files.
- ✓ 3D models which do not contain any object attributes.
- ✓ 3D models with objects that do not contain parametric intelligence.
- ✓ Architectural design is created but alternative solutions are not compared via BIM.

LEVEL 1-PERFORMED: The BIM is implemented to achieve the process purpose and used for performing base practices and producing standalone BIM outcomes. However, BIM has not been integrated into facility life cycle phases and there are no significant BIM based collaboration and data exchange between the facility life cycle phases and the processes.

The following BIM attributes demonstrate the achievement of this level.

BIM Attribute 1.1) Performing BIM: The “Performing BIM” BIM attribute is a measure of the extent to which the defined BIM outcomes are achieved. As a result of the full achievement of this BIM attribute:

a) The process achieves its defined BIM outcomes.

Generic Practices for “Performing BIM” BIM attribute:

GP 1.1.1 Achieve the BIM outcomes.

- ✓ Perform the intent of the base practices.
- ✓ Produce BIM work products that evidence the BIM outcomes.

Generic BIM Work Products for “Performing BIM” BIM attribute: Some example BIM work products providing evidence of achieving the BIM outcomes are as follows:

1. BIM work products. (Achievement a)
- ✓ BIM work products exist that provide evidence of the achievement of the BIM outcome.

Generic Resources for “Performing BIM” BIM attribute: Some example resources used to perform the intent of the base practices are as follows:

1. Hardware, (Achievement a)
- ✓ Devices, (Powerful workstations, servers, tablet/mobile devices, wireless hand held devices, RFID tags, cameras installed on site, voice recording, laser scanners, etc.)
- ✓ Network, (WLAN, LAN, etc.)
- ✓ Security services,
- ✓ Services, (Cloud storage services, etc.)
- ✓ Databases,
2. Software applications, (Achievement a)

- ✓ BIM authoring tools for model generation,
  Architectural (ArchiCAD, Bentley Architecture, Digital Project, Revit, Bentley Generative Components, DProfiler, etc.)
  Structural (Revit Structures, Tekla Structures, etc.)
  MEP (CAD Duct, CAD MEP, Revit MEP, MagicCAD, etc.)
- ✓ Analysis Tools,
  Structural (RAM, Robot Millenium, Strand, ETABS, SAP, etc.)
  Estimating (DProfiler, Sage Timberline, Innovaya, Vico Cost Estimation, Navisworks, Revit, and etc.)
  Scheduling (Primavera, Strategic Project Solutions, Vico Control, Synchro, etc.)
  Coordination (Navisworks, Newforma, etc.)
  Rule-Checking (Solibri, etc.)
  Survey Control (Trimble RealWorks, etc.)
  Laser Scanning (Cloudworx, etc.)
  Energy (TraneTrace, EnergyPlus, etc.)
- ✓ Construction management tools,
- ✓ Facility maintenance information tools,
- ✓ Computer aided facility management tools, (ARCHIBUS, Trimble Centerstone, etc.)
- ✓ Computerized maintenance management system, (IBM Maximo, etc.)
- ✓ Asset management software, (IBM Maximo, etc.)
- ✓ Building automation system (Building management systems, etc.),
- ✓ Virtual Reality Services (Mixed reality, Augmented reality, etc.)
- ✓ Location services, (GPS, etc.).

3. Process owners and stakeholders, (Achievement a)

- ✓ Contractors, managers, engineers, designers, owners, operators, etc.

BIM Attribute 1.2) BIM Skills: The “BIM Skills” BIM attribute is a measure of the extent to which the organization prefer to work with BIM trained and/or BIM experienced employees. As a result of the full achievement of this BIM attribute:

a) Staff with BIM skills and/or BIM experience are employed,
b) Employees are supported in taking BIM trainings,
c) BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged.

Generic Practices for “BIM Skills” BIM attribute:

GP 1.2.1 Employ staff with BIM skills and/or BIM experience.

- ✓ Include BIM in job advertisements descriptions,
- ✓ Hire the staff who have the required BIM skills and/or have previous BIM experience,

GP 1.2.2 Support employees to take BIM trainings.

- ✓ Allocate a budget for BIM trainings,
- ✓ Determine employees who need to take BIM training,
- ✓ Conduct BIM trainings and/or send employees to BIM trainings regularly.

GP 1.2.3 Assign the BIM related processes to the employees with BIM trained and/or BIM experience or encourage peer learning to share BIM knowledge.

- ✓ Determine BIM related processes,
- ✓ Determine BIM roles and responsibilities of the processes,
- ✓ Assign the BIM roles and responsibilities to the BIM skilled employees.
- ✓ Form a team including a BIM skilled employee to support disseminating BIM knowledge to other team members.

Generic BIM Work Products for “BIM Skills” BIM attribute: Some example BIM work products providing evidence of achieving the BIM attribute outcomes are as follows:

1. Employees with BIM experience, (Achievement a, b)
2. Employees who took BIM trainings, (Achievement a,b)
3. BIM training records, (Achievement b)
4. Job advertisement descriptions, (Achievement a)
5. A strategy for assigning the BIM roles and responsibilities to the BIM skilled employees (Achievement c).
6. BIM roles are integrated into organization scheme (Achievement c).

Generic Resources for “BIM Skills” BIM attribute: Some example resources used to perform the intent of the base practices are as follows:

1. Employees with BIM skills and/or BIM certification, (Achievement a, b, c)
   - ✓ BIM engineer, BIM architect, BIM coordinator, BIM director, information manager, etc.
2. BIM expert, (Achievement a, b)
   - ✓ BIM consultant, BIM trainer employed within the organization, etc.
3. BIM training budget, (Achievement b)
4. Standards for BIM trainings. (Achievement b)

LEVEL 2-INTEGRATED: The previously performed BIM is now implemented using an integrated BIM capable of enabling collaboration between the project stakeholders and data exchange throughout the facility life cycle phases and the processes.

The following process attributes, together with the previously defined BIM attributes, demonstrate the achievement of this level:

BIM Attribute 2.1) BIM Collaboration: The “BIM Collaboration” BIM attribute is a measure of the extent to which the BIM is used to support the collaboration and information exchange between the facility life cycle phases and the processes. As a result of the full achievement of this BIM attribute:

a) Requirements and strategies are defined for supporting BIM collaboration between internal and external parties,
b) Requirements and strategies are defined for exchanging the model and the facility information between phases and processes,
c) Defined BIM collaboration strategies are implemented,
d) Defined exchange strategies of the model and the facility information are implemented.

Generic Practices for “BIM Collaboration” BIM attribute:

GP 2.1.1 Define requirements and strategies to support BIM collaboration between internal and external parties.

- ✓ Determine internal and external parties who are required to be included in BIM collaboration.
- ✓ Determine requirements for BIM collaboration.

- ✓ Define strategies to support BIM collaboration between internal and external parties.

GP 2.1.2 Define requirements and strategies for exchanging the model and facility information between phases and processes by using BIM.

- ✓ Determine requirements for exchanging the model and the facility information between phases and processes in which BIM is utilized,
- ✓ Define strategies for exchanging the model and the facility information between the phases and the process.

GP 2.1.3 Implement BIM collaboration between internal and external parties in terms of defined strategies.

- ✓ Collaborate with internal and external parties by using BIM.

GP 2.1.4 Implement defined strategies for exchanging the model and the facility information.

- ✓ Exchange the model and the facility information by using BIM.

Generic BIM Work Products for "BIM Collaboration" BIM Attribute: Some example BIM work products providing evidence of achieving the BIM attribute outcomes are as follows:

1. Shared models for collaboration/coordination, (Achievement c)
2. BIM Execution Plan (BEP), (Achievement a, b)

   The parts, which are included but not limited to in BEP, are;

   - ✓ BIM vision is defined.
   - ✓ BIM project goals are defined.
   - ✓ BIM uses are identified.
   - ✓ Project deliverables and BIM deliverables are identified.
   - ✓ BIM process is explained.
   - ✓ Modeling requirements (Naming of files, file interchange based on IFC, coding, information exchange/collaboration platform, LOD level per design phase, LOMD, aspect models, etc.) are defined.
   - ✓ Requirements such as project partners, meetings, project planning, simulations and analyses, quality control, risks and possible control measures, etc. are defined.
   - ✓ Required building information exchange standards, such as COBie, are specified.
   - ✓ BIM collaboration procedures are defined for overall project.
   - ✓ Quality assurance and quality control procedures are defined.
3. Documents, reports, etc. which defines BIM collaboration strategies and/or procedures, (Achievement a)
4. Documents, reports, work flows, etc. which defines the model and the facility information exchange strategies and/or methods, (Achievement b)
5. BIM coordination rooms which is used to coordinate design from different disciplines based on BIM, (Achievement c)
6. Clash detection reports such as meeting minutes, (Achievement c)
7. Existence of exchange strategies of the model and facility information such as file and folder structures created on common data environments and /or shared server and naming conventions of these files, folders and BIM deliverables, (Achievement d)
8. Existence of defined standard data formats for exchanging the model and the facility information such as ".dwg", ".pdf", etc., (Achievement d)

9. Construction Operations Building information exchange (COBie) which contains life-cycle information captures from the model, (Achievement d)
10. Information Delivery Manuals (IDM) which includes information about how to exchange model. (Achievement d)

Generic Resources for "BIM Collaboration" BIM attribute: Some example resources used to perform the intent of the base practices are as follows:

1. Construction information and documentation standards and guidelines, (Achievement a, b)
- ✓ National BIM Guide,
- ✓ BS1192:2007 – Collaborative production of architectural, engineering and construction information – Code of Practice,
- ✓ PAS 1192 Part 2:2013 – Specification for information management for the capital/delivery phase of construction projects using building information modeling,
- ✓ PAS1192 Part 3:2014 – Specification for information management for the operational phase of assets using building information modeling,
- ✓ BS 1192 Part 4:2014 – Collaborative production of information – Part 4 Fulfilling employers' information requirements using COBie – Code of Practice,
- ✓ PAS 1192 Part 5:2015 – Specification for security minded building information modeling, digital built environments and smart asset management,
- ✓ ASHRAE Guideline 4-2008 (RA 2013) Preparation of Operating and Maintenance Documentation for Building Systems,
- ✓ AEC BIM Protocol,
- ✓ COBie which captures life-cycle information from the model and provides information delivery to facility managers,
- ✓ IDM which document model exchange to support sustainable models.

2. Software, (Achievement c, d)
- ✓ Collaboration tools,
  BIM collaboration software (Autodesk BIM 360 Team, Autodesk Collaboration for Revit),
  Construction document management (Aconex, Autodesk BIM 360 docs),
  Construction project management in the cloud (Autodesk Constructware),
  Project information management and collaboration cloud services (Bentley Projectwise),
  Collaboration and data management software (Autodesk Vault).

3. Hardware, (Achievement a, b, c, d)
- ✓ Common data environments (Shared storage locations and servers, etc.)
- ✓ Services, (Cloud storage services, etc.).

4. Process owners and stakeholders, (Achievement a, b, c, d)
- ✓ External parties,
- ✓ Internal parties.

BIM Attribute 2.2) Interoperability: The "Interoperability" BIM attribute is a measure of the extent to which interoperability and flexible data exchange between BIM software applications are supported. As a result of the full achievement of this BIM attribute:

a) Interoperable formats are made available and used to support data exchange between BIM software and other construction software applications.

Generic Practices for "Interoperability" BIM Attribute:

GP 2.2.1 Facilitate interoperability between BIM software and other construction software applications.

- ✓ Identify interoperability requirements between BIM software and other construction software
- ✓ Select appropriate interoperable formats to support flexible data exchange.

Generic BIM Work Products for "Interoperability" BIM Attribute: Some example BIM work products which provide evidence of achieving the BIM attribute outcomes;

1. Models and facility information represented with interoperable formats, (Achievement a)
- ✓ Direct links such as Application Programming Interface (API), integrates software systems and enables exporting data from one system and importing data to another system.
- ✓ Product data models such as Industry Foundation Classes (IFC) integrate processes by exchanging data in neutral formats.
- ✓ Proprietary exchange formats connect applications of same software vendor,
- ✓ XML schemas selected based on information and workflows.

Generic Resources for "Interoperability" BIM Attribute: Some example resources, which are used to perform the intent of the base practices, are;

1. Interoperable formats, (Achievement a)
- ✓ Direct and proprietary links, (ArchiCad's GDL, Revit's Open API, or Bentley's MD)
- ✓ Product data model formats, (Industry Foundation Classes (IFC), STP, EXP, CIS/2)
- ✓ Proprietary file exchange formats, (DXF (Data eXchange Format by Autodesk), SAT for Spatial Technology, STL for stereolithography, and 3DS for 3D-Studio)
- ✓ XML schemas, (AecXML, Obix, AEX, bcXML, AGCxml)

2. Plugins. (Achievement a)

LEVEL 3-OPTIMIZED: The previously integrated BIM is now used at the enterprise level and is continuously improved to support organizations' business goals.

The following process attributes, together with the previously defined BIM attributes, demonstrate the achievement of this level:

BIM Attribute 3.1) Corporate-wide BIM Deployment: The Corporate-wide BIM Deployment BIM attribute is a measure of the extent to which BIM is diffused to each of the facility life cycle phases and the processes and embraced by all team members. As a result of the full achievement of this BIM attribute:

a) Model is used for all processes and embraced by all team members,
b) Required facility information for different processes are extracted from the model and provided for the use of all team members,
c) Change management and synchronization of the model are established and the model updates are tracked,
d) BIM objects and facility information are collected in a library for reusing this information on future projects.

Generic Practices for "Corporate-wide BIM Deployment" BIM attribute:

GP 3.1.1) Use model for all processes and make model embraced by all team members.

- ✓ Define company-wide BIM execution plan,
- ✓ Make the model available and usable for processes in which BIM implementation is critical,
- ✓ Support all team members to use BIM for these BIM required processes.

GP 3.1.2) Enable all team members to extract and use the required facility information for different processes.

- ✓ Determine required type and amount of information to be extracted from the model,
- ✓ Create model views by extracting facility information from the model,
- ✓ Make these model views available for all team members in the required format.

GP 3.1.3) Apply change management for tracing, archiving, and synchronizing updates of the model.

- ✓ Establish change management for version control of the models,
- ✓ Make internal and external parties get notifications whenever the model is updated,
- ✓ Enable synchronization of model for supporting distributed facility information generation and management.

GP 3.1.4 Reuse BIM objects and facility information on future projects.

- ✓ Develop Custom 3D object libraries for reusing BIM objects on future projects,
- ✓ Create benchmarks by collecting data on project and project-specific BIM usage for critical decisions in future projects,
- ✓ Develop BIM based decision making mechanism for critical decisions.

Generic BIM Work Products for "Corporate-wide BIM Deployment" BIM attribute: Some example BIM work products providing evidence of achieving the BIM attribute outcomes are as follows:

1. Using the model in all BIM related processes, (Achievement a)
   - ✓ Creating As-Built models,
   - ✓ Gathering real-time progress data during construction,
   - ✓ Conducting quality assurance and quality control,
   - ✓ Using virtual reality associated with model,
   - ✓ Digital fabrication from model,
   - ✓ Supporting project site logistics by using the model,
   - ✓ Equipment positioning and movement on the site,
   - ✓ Model is accessed regardless of location/device.
2. Using model by integrating data coming from different software applications for data analysis and data extraction, (Achievement a, b)
   - ✓ Linking work orders, O&M tasks and related O&M data with model,
   - ✓ Root-cause analysis of problems related to assets,
   - ✓ Visualization of the model and existing conditions together,
3. Model views, which are created according to requirements of different processes, (Achievement b)
4. Strategy for managing change requests coming from client, site, etc., (Achievement c)
5. Version control of the model according to change requests, (Achievement c)
6. Custom libraries such as 3D object libraries, benchmarks, and ontologies. (Achievement d)

Generic Resources for "Corporate-wide BIM Deployment" BIM attribute: Some example resources used to perform the intent of the base practices are as follows:

1. Company-wide BIM execution plan, (Achievement a)
2. International Standards, (Achievement b)
   - ✓ Model View Definitions.
3. Software, (Achievement a, b, c)
   - ✓ Multi user BIM authoring and analyzing tools,

- ✓ BIM collaboration software (Autodesk BIM 360 Team, Autodesk Collaboration for Revit),
- ✓ Virtual Reality Services (Mixed reality, Augmented reality, etc.)
- ✓ Location services, (GPS, etc.),
- ✓ Databases to store, gather and integrate the model and facility information,
- ✓ Enterprise Resource Planning (ERP) systems integrated with BIM.

3. Hardware, (Achievement a, b, c)

- ✓ Devices (Tablet/mobile devices, wireless hand held devices, RFID tags, cameras installed on site, voice recording, laser scanners, etc.),
- ✓ Common data environments,
- ✓ Services, (Cloud storage services, etc.).

4. BIM server, (Achievement c)

- ✓ Autodesk Collaborative Project Management
- ✓ Bentley ProjectWise Integration Server
- ✓ BIM Server
- ✓ Drofus
- ✓ EuroSTEP Share-A-Space Model Server
- ✓ Graphisoft ArchiCad BIM Server
- ✓ Horizontal Glue™
- ✓ Jotne EDM Model Server
- ✓ Oracle Primavera and AutoView Primavera on Oracle

BIM Attribute 3.2) Continuous BIM Improvement: The "Continuous BIM Improvement" BIM attribute is a measure of the extent to which changes to the BIM practices are planned from analysis of common causes of variation in BIM usage, and from investigations of innovative BIM approaches for the deployment of BIM. As a result of the full achievement of this BIM attribute:

a) A feedback mechanism is created to identify common causes of variations in BIM usage,
b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified,
c) An implementation strategy is established to achieve BIM improvement objectives.

Generic Practices for "Continuous BIM Improvement" BIM attribute:

GP 3.2.1 Create a feedback mechanism to identify common causes of variations in BIM usage.

- ✓ Gather data from all of the facility life cycle phases and the processes,
- ✓ Transform BIM data into appropriate formats for data analytics,
- ✓ Analyze the gathered data to identify common causes of variations in BIM usage.

GP 3.2.2 Identify improvement opportunities to eliminate variations in BIM usage based on new BIM technology trends and best practices.

- ✓ Identify and evaluate industry best practices,
- ✓ Follow BIM technology trends,
- ✓ Identify improvement opportunities based on determined causes of variations, best practices, and technology trends.

GP 3.2.3 Define an implementation strategy to take BIM improvement opportunities.

- ✓ Evaluate proposed BIM improvements to determine their benefits and expected impacts on business objectives,
- ✓ Classify and prioritize improvements based on their impacts,

- ✓ Plan the implementation of the approved improvement objectives.

Generic BIM Work Products for "Continuous BIM Improvement" BIM attribute: Some example BIM work products providing evidence of achieving the BIM attribute outcomes are as follows:

1. Mechanism for identifying and documenting BIM variations, (Achievement a, b)
2. Innovation meetings within the organization, (Achievement b)
3. List of improvement opportunities, (Achievement b)
4. Meeting minutes, (Achievement c)
5. Strategy to implement BIM improvement objectives, (Achievement c)

Generic Resources for "Continuous BIM Improvement" BIM attribute: Some example resources used to perform the intent of the base practices are as follows:

1. Software for identification of problems in BIM utilizations, (Achievement a)
   - ✓ Project management tools,
   - ✓ Data analytics tools,
2. Documentation/reports of software vendors about new BIM technologies such as software applications, services, etc., (Achievement b)
3. Reports about best practices of BIM usage in industry, (Achievement b)
4. Technical reports about new BIM technologies, (Achievement b)
5. Employees, (Achievement a)

BIM Attribute Rating Scale:

(N) Not Achieved: There is little or no evidence of achievement of the defined BIM attribute in the assessed process.

(P) Partially Achieved: There is some evidence of an approach to achieve the defined BIM attribute in the assessed process.

(L) Largely Achieved: There is evidence of systematic approach to achieve the defined BIM attribute in the assessed process.

(F) Fully Achieved: There is evidence of a complete and systematic approach to achieve the defined BIM attribute in the assessed process.

(N/A) Not Applicable: There is not enough evidence to assess the defined BIM attributes in the assessed process.

In order to have composite rating we aggregated the single ratings of BIM attribute outcomes. First, ordinal ratings F, L, P, N are converted into interval values 3, 2, 1, 0, respectively. Later, median of the single ratings are calculated. If there is odd number of value, the result is the middle value. On the other hand, if there is even number of data, the minimum of the two middle values is selected. The final result is converted back to the corresponding ordinal value. The achieved BIM Capability Level is derived according to BIM attributes ratings which are presented in the Table 2 below.

Table 2: Rating Scale of BIM-CAREM

BIM Att. / Cap. Level	BIM A1.1 Performing BIM	BIM A1.2 BIM Skills	BIM A2.1 BIM Collaboration	BIM A2.2 Interoperability	BIM A3.1 Corporate-wide BIM Deployment	BIM A3.2 Continuous BIM Improvement
L0 - Incomplete						
L1 - Performed	L / F	L / F				
L2 - Integrated	F	F	L / F	L / F		
L3 - Optimized	F	F	`F	F	L / F	L / F
L / F – BIM attribute is required to be achieved Largely or Fully. F – BIM attribute is required to be achieved Fully.						

APPENDIX D – RECURRING KEYWORDS IN BIM USES AND CLUSTERED BIM USES

BIM uses facilitated for development of BIM Process Reference Model

Key Word	BIM Use	Resource	Count
Cost	Cost Estimation	BEP of Pennsylvania State University	3
	Cost estimating	Green BIM	
	Integration of Model with Costs (5D)	The Business Value of BIM for Construction in Major Global Markets	
	Model based estimating	The Perceived Value of BIM in U.S. Building Industry	1
	Value Engineering	The Business Value of BIM for Construction in Major Global Markets	1
Analysis	Building System Analysis	BEP of Pennsylvania State University	1
	Engineering Analysis	BEP of Pennsylvania State University	6
	Creating and analyzing models	Green BIM	
	BIM Analysis and Simulation Capabilities Produce a More Well-Reasoned Design	The Business Value of BIM for Owners	
	Simulation and analysis to optimize	The Business Value of BIM for Construction in Major Global Markets	
	Using BIM tools to analyze models, but not creating own models	Green BIM	
	Use of BIM to stimulate total building %65	Green BIM	
	Energy Analysis	BEP of Pennsylvania State University	4
	Energy performance	Green BIM	
	Using BIM for building performance	Green BIM	
	Use of BIM to simulate energy performance %73	Green BIM	
	Structural Analysis	BEP of Pennsylvania State University	1
	Site Analysis	BEP of Pennsylvania State University	1
	Carbon emission analysis	Green BIM	1
	Environmental analysis	The Perceived Value of BIM in U.S. Building Industry	1
	Forensic analysis	The Perceived Value of BIM in U.S. Building Industry	1
Schedule	Building (Preventative) Maintenance Scheduling	BEP of Pennsylvania State University	1
	Construction sequencing	The Perceived Value of BIM in U.S. Building Industry	2

	Construction Work Packaging and Sequencing	Smart Market Brief: BIM Advancements No.1	
	Phase Planning (4D Modeling)	BEP of Pennsylvania State University	2
	Integration of Model with Schedule (4D)	The Business Value of BIM for Construction in Major Global Markets	
Plan	Disaster Planning	BEP of Pennsylvania State University	1
	Site Utilization Planning	BEP of Pennsylvania State University	1
	3D Control and Planning	BEP of Pennsylvania State University	1
	Plant selection with water use	Green BIM	1
	BIM Planning	Smart Market Brief: BIM Advancements No.1	1
	Crew Locations and Workforce Planning	Smart Market Brief: BIM Advancements No.1	1
	Project planning	The Business Value of BIM for Construction in Major Global Markets	1
	Virtual Jobsite Planning and Logistics	The Business Value of BIM for Construction in Major Global Markets	1
	Safety Planning/Training	The Business Value of BIM for Construction in Major Global Markets	1
	Agreed-Upon Processes for Advanced Tool Use (e.g., BIM Execution Plan)	Measuring the Impact of BIM on Complex Buildings	1
Manage	Asset Management	BEP of Pennsylvania State University	1
	Space Management and Tracking	BEP of Pennsylvania State University	1
	Supply Chain Management	The Business Value of BIM for Construction in Major Global Markets	1
	Facilities management	The Perceived Value of BIM in U.S. Building Industry	1
	Pass on the model to those who are responsible for continued management of the building	NBS National BIM Report	2
	Managing the Model for Owner Beyond Closeout	The Business Value of BIM for Construction in Major Global Markets	
	Manage Project Schedule	Information Mobility	1
Visualization	Visualization for Stakeholder Engagement	The Business Value of BIM for Owners	1
	Visualization of the Design Intent	The Business Value of BIM for Construction in Major Global Markets	2
	BIM Visualization Enables a Better Understanding of Proposed Design	The Business Value of BIM for Owners	
	Visualization	The Perceived Value of BIM in U.S. Building Industry	1

Coordination	Spatial Coordination Among Models of Work of Major Trades to Reduce Conflicts the Field	The Business Value of BIM for Owners	1
	There Are Fewer Problems During Construction Related to Design Errors, Coordination Issues or Construction Errors	The Business Value of BIM for Owners	1
	Multi-Trade Coordination	The Business Value of BIM for Construction in Major Global Markets	1
	Coordinate Building Systems to Improve Building Energy Performance	The Business Value of BIM for Construction in Major Global Markets	1
Review	Design Reviews	BEP of Pennsylvania State University	1
	Drawing/2D Review/Markup	Information Mobility	1
	BIM/3D Review/Markup	Information Mobility	1
	Mapping & GIS Review/Markup	Information Mobility	1
	Code review	The Perceived Value of BIM in U.S. Building Industry	1
	Code Validation	BEP of Pennsylvania State University	1
Site	Project Site Logistics	Smart Market Brief: BIM Advancements No.1	1
	Integrating Model with GPS to Control Construction Equipment Onsite	The Business Value of BIM for Construction in Major Global Markets	1
	Equipment Positioning and Movement on the Site	Smart Market Brief: BIM Advancements No.1	1
	Ensure Onsite Information Is Current	Information Mobility	1
	Ensure Site Safety	Information Mobility	1
	Model-Driven Robotics Onsite	The Business Value of BIM for Construction in Major Global Markets	1
	Through Computers Onsite (“Kiosks”)	The Business Value of BIM for Construction in Major Global Markets	1
	Model-Driven Layout in the Field	The Business Value of BIM for Construction in Major Global Markets	1
Fabrication	Digital Fabrication	BEP of Pennsylvania State University	2
	Direct fabrication	The Perceived Value of BIM in U.S. Building Industry	
	Model-Driven Prefabrication by Trades/Fabricators	The Business Value of BIM for Owners	2
	Model-Driven Prefabrication	The Business Value of BIM for Construction in Major Global Markets	
	Create Tighter Building Envelope Through BIM-Enhanced Prefabrication	The Business Value of BIM for Construction in Major Global Markets	1
Design	Construction System Design	BEP of Pennsylvania State University	1

	Design Authoring	BEP of Pennsylvania State University	4
	Using BIM-Authoring Tool to Prepare Preliminary Schematic Design	The Business Value of BIM for Owners	
	Project Design Developed in BIM	Measuring the Impact of BIM on Complex Buildings	
	Alternative development	The Perceived Value of BIM in U.S. Building Industry	
	HVAC design	Green BIM	1
	Electrical design	Green BIM	1
	Building design	The Perceived Value of BIM in U.S. Building Industry	1
	Schematic design	The Perceived Value of BIM in U.S. Building Industry	1
	Conceptual design	The Perceived Value of BIM in U.S. Building Industry	1
	Detailed design	The Perceived Value of BIM in U.S. Building Industry	1
Sustain	Sustainability (LEED) Evaluation	BEP of Pennsylvania State University	2
	LEED certification	The Perceived Value of BIM in U.S. Building Industry	
Program	Program/Massing studies	BEP of Pennsylvania State University	2
	Programming	BEP of Pennsylvania State University	
As built	As-Built model	The Perceived Value of BIM in U.S. Building Industry	3
	Preparing Final As-Built Model for Owner	The Business Value of BIM for Construction in Major Global Markets	
	Record Modeling	BEP of Pennsylvania State University	
	Adding Maintenance and Operations Data to Model for Owner	The Business Value of BIM for Construction in Major Global Markets	2
	Model management for owners	The Business Value of BIM for Construction in Major Global Markets	
	Existing Conditions Modeling	BEP of Pennsylvania State University	1
Rule Checking	Safety rule checking in the model	Smart Market Brief: BIM Advancements No.1	1
Constructability	Building assembly	The Perceived Value of BIM in U.S. Building Industry	1
	Construction	The Perceived Value of BIM in U.S. Building Industry	1
	Productization	The Business Value of BIM for Construction in Major Global Markets	1
Laser-scanning	Laser scanning	The Business Value of BIM for Construction in Major Global Markets	1
	Laser Scanning During Construction to Validate Compliance with the Model	The Business Value of BIM for Construction in Major Global Markets	1

	Laser Scanning Capturing Existing Conditions into a Model Before Construction	The Business Value of BIM for Construction in Major Global Markets	1
Clash detection	Clash detection	The Perceived Value of BIM in U.S. Building Industry	1
Feasibility/Bid	Bid prep	The Perceived Value of BIM in U.S. Building Industry	1
	Feasibility studies	The Perceived Value of BIM in U.S. Building Industry	1
Quantity	Determining Quantities from a Model	The Business Value of BIM for Construction in Major Global Markets	1
Real-time	Status/Progress Monitoring	The Business Value of BIM for Construction in Major Global Markets	1
	Analyze Real-Time Field Data	Information Mobility	1
	Gather Real-Time Data from Field	Information Mobility	1
Green	Green building certification	Green BIM	1
	Lighting activities	Green BIM	1
	Renewable energy	Green BIM	1
Edit	BIM/3D Editing or Authoring	Information Mobility	1
	Mapping & GIS Editing or Authoring	Information Mobility	1
	Edit/Annotate Documents	Information Mobility	1
	Interact with 3D Models	Information Mobility	1
	See File Properties	Information Mobility	1

BIM uses facilitated for development of BIM Measurement Framework

Key Word	**BIM Use**	**Resource**	**Count**
Collaboration	Work collaboratively on design	UK's National BIM Reports	2
	Collaborate with owners/design firms	The Business Value of BIM for Construction in Major Global Markets	
	Low Level of Collaboration	Smart Market Brief	1
	Better Collaboration Among Team Members	Information mobility	3
	Improved team member collaboration	Smart Market Brief	
	Improved Teamwork and Collaboration	Measuring the Impact of BIM on Complex Buildings	
	Collaborate with Project Teams Within Firm	Information Mobility	1
	Collaborate with Others Outside Firm	Information Mobility	2
	Developing external Collaborative BIM Processes	The Business Value of BIM for Construction in Major Global Markets	

Communicate	Mobile Apps for Communication	Smart Market Brief	1
	Maintain of CE Communication with Site	Information Mobility	1
	Communicate with Owner	Information Mobility	1
	Enhanced Communication Among Team Members	Measuring the Impact of BIM on Complex Buildings	1
Share	Share models with design team members outside your organization	UK's National BIM Reports	1
	Share models inside your organization, across disciplines	UK's National BIM Reports	1
	Shared Storage Locations	Smart Market Brief,	2
	Shared Storage Location	Information Mobility	
	Increased Ability to Share Project Documents	Information Mobility	1
	Securely Share Documents/Revisions Across Project Teams	Information Mobility	1
	Share Files with Project Team Members	Information Mobility	1
	Share Files with Other Applications	Information Mobility	1
Access	Easy Access to Project Information Regardless of Location/Device	Information Mobility	1
	Access to Current Project Information	Information Mobility	1
	Access to Information for Workers Onsite	Information Mobility	1
	Access Project Information Onsite	Information Mobility	1
	Provide Access to 3D CAD/BIM Onsite	Information Mobility	1
	Access Software for Company Business Activities	The Business Value of BIM for Construction in Major Global Markets	1
	Host One or More Models for Team Access	The Business Value of BIM for Construction in Major Global Markets	1
	Access Software for Project Activities	The Business Value of BIM for Construction in Major Global Markets	1
Team	Low Level of Team Interest/Support	Smart Market Brief	1
	GC's Early Involvement With Design Team Models	Measuring the Impact of BIM on Complex Buildings	1
Interoperable	Platform Challenges	Smart Market Brief	1
	Platform Compatibility	Smart Market Brief	1
	Software Customization/ Interoperability Solutions	The Business Value of BIM for Construction in Major Global Markets	1
	Software integration	Green BIM	1
	Integrated output from different building systems	Green BIM	1

	Integrating with Model for Punch List/Snag List and Close-Out Activities	The Business Value of BIM for Construction in Major Global Markets	1
Customization	Developing Custom 3D Libraries	The Business Value of BIM for Construction in Major Global Markets	1
Training	BIM Training	The Business Value of BIM for Construction in Major Global Markets	2
	Manage/Train Workforce	Information Mobility	

BIM uses facilitated for development of BIM Generic Resources

Key Word	BIM Use	Resource	Count
Device	Laptop Computer	Information Mobility	1
	Desktop Computer	Information Mobility	1
	iOS device (iPad, iPhone)	Information Mobility	1
	Android Device	Information Mobility	1
	BlackBerry Device	Information Mobility	1
	Windows Mobile Device	Information Mobility	1
	Netbook	Information Mobility	1
	Cameras	Information Mobility	1
	GPS Location Services	Information Mobility	1
	Voice Recording	Information Mobility	1
	New/Upgraded Tablets/Mobile devices	The Business Value of BIM for Construction in Major Global Markets	1
	On Computer in the Job Trailer	The Business Value of BIM for Construction in Major Global Markets	1
	On Wireless Handheld Devices	The Business Value of BIM for Construction in Major Global Markets	1
	On Large or Multi-Screen Display(s) in the Job Trailer (“BIM Cave”)	The Business Value of BIM for Construction in Major Global Markets	1
	New/Upgraded Desktop Machines	The Business Value of BIM for Construction in Major Global Markets	1
2D/drawing	Produce 2D digital drawings	NBS National BIM Report	1
	Digital Documents and Drawing Files	Information Mobility	1
	Paper Documents and Drawings	Information Mobility	1

	Utilize Drawings	Information Mobility	1
	2D Drawings	Information Mobility	1
	Drawing/2D Editing or Authoring	Information Mobility	1
	Digital PDF Files	Information Mobility	1
Format/storage	Digital Model Files	Information Mobility	1
	PDFs	Information Mobility	1
	Images	Information Mobility	1
	3D Models	Information Mobility	1
	Videos	Information Mobility	1
	Handwritten Documents/Notes	Information Mobility	1
	Microsoft Office Documents	Information Mobility	1
	Instant Messaging	Information Mobility	1
	Online Meetings	Information Mobility	1
	Produce 3D digital models	NBS National BIM Report	1
	Use 3D information models, but not ones that included all the building information	NBS National BIM Report	1
	FTP	Information Mobility	1
	Work with Large Digital Files (Greater than 50 MG)	Information Mobility	1
	Export Files to Local Device	Information Mobility	1
Policy	Owner BIM Advocacy	Smart Market Brief: BIM Advancements No.1	1
	Modelling standards	Green BIM	1
Cloud	Ability to Store and Access Project Information in the Cloud	Smart Market Brief: BIM Advancements No.1	1
	BIM Functionality in the Cloud	Smart Market Brief: BIM Advancements No.1	1
	Cloud Storage Services	Information Mobility	1
	Use Point Cloud Information	Information Mobility	1
	Point Clouds	Information Mobility	1
Software	BIM software	The Business Value of BIM for Construction in Major Global Markets	1
	Information/Document Management System	Information Mobility	1
	Augmented Reality to Visualize the Model and Existing Conditions Together	The Business Value of BIM for Construction in Major Global Markets	1
	Augmented reality to blend models with live camera views of reality	The Business Value of BIM for Construction in Major Global Markets	1

BIM uses which are not clustered

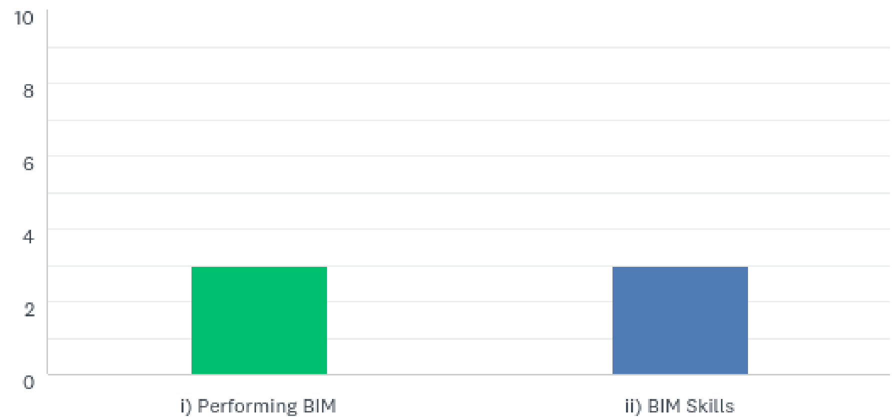
Key Word	BIM Use	Resource	Count
Productivity	Improved productivity	Smart Market brief BIM advancements, 2015 Measuring the impact of BIM on complex buildings, 2015 Measuring the impact of BIM on complex buildings,2013 Information mobility BIM Smart Market	4
	Desire to Improve Productivity	2013 Information mobility BIM Smart Market	
	Improved Labor Productivity	2015 Measuring the impact of BIM on complex buildings	
	Percentage of Improved Labor Productivity	2015 Measuring the impact of BIM on complex buildings	
	Accelerate project completion	Smart Market brief BIM advancements, 2015 Measuring the impact of BIM on complex buildings,2015 Measuring the impact of BIM on complex buildings	3
	Compressed Schedule Results in Accelerated Project Completion	2015 Measuring the impact of BIM on complex buildings	
	Percentage of Accelerated Project Completion Due to Schedule Compression Percentage of RFI Reduction	2015 Measuring the impact of BIM on complex buildings	
	Improve Project Quality	2013 Information mobility BIM Smart Market	1
	Increase Portability	2013 Information mobility BIM Smart Market	1
	Reuse Information on Future Projects	2013 Information mobility BIM Smart Market	1
	Reduce Project Risk	2013 Information mobility BIM Smart Market	1
	Reduced errors and omissions	2014 Business Value of BIM in Global Markets, Smart Market brief BIM advancements	2
	Reduced unanticipated problems	Smart Market brief BIM advancements	
	Enhancing your organization’s image	2014 Business Value of BIM in Global Markets	1
	Reducing overall project duration	2014 Business Value of BIM in Global Markets, 2014 The Business Value of BIM for Owners	2
	Use of BIM Has a Beneficial Impact on Project Schedule	2014 The Business Value of BIM for Owners	
	Marketing new business	2014 Business Value of BIM in Global Markets	1
	Industrialization of construction	2014 Business Value of BIM in Global Markets	1
	Reduced cycle time of workflows	2014 Business Value of BIM in Global Markets, 2015 Measuring the impact of BIM on complex buildings	2

	Reduced Amount of Out-of-Sequence Work Due to Earlier Problems	2015 Measuring the impact of BIM on complex buildings	
	Faster client approval cycles	2014 Business Value of BIM in Global Markets, 2015 Measuring the impact of BIM on complex buildings	2
	Improved Achievement of Planned Schedule Milestone Dates	2015 Measuring the impact of BIM on complex buildings	
	Faster regulatory approval cycles	2014 Business Value of BIM in Global Markets	1
	Improved Accuracy and Completeness of Bids	2015 Measuring the impact of BIM on complex buildings	1
	Reduced Number of RFIs	2015 Measuring the impact of BIM on complex buildings	1
	Reduced Rework	2015 Measuring the impact of BIM on complex buildings	1
	Reduced Reportable Safety Incidents	2015 Measuring the impact of BIM on complex building, 2015 Measuring the impact of BIM on complex buildings	2
	Percentage Reduction in Number of reportable Safety Incidents	2015 Measuring the impact of BIM on complex buildings	
	Reduced Material Waste	2015 Measuring the impact of BIM on complex buildings, 2014 Business Value of BIM in Global Markets	2
	Better Waste Management	2014 Business Value of BIM in Global Markets	
	Higher-Scaled Metrics	2015 Measuring the impact of BIM on complex buildings, 2014 Business Value of BIM in Global Markets	2
	Performance metrics: Early-stage BIM users need to compare performance metrics from pre-BIM projects to establish the value of basic BIM benefits such as virtual coordination and to justify their continued BIM investments.	2014 Business Value of BIM in Global Markets	
	BIM-Integrated Project Meetings	2015 Measuring the impact of BIM on complex buildings	1
	Early Trade Contractor Involvement	2015 Measuring the impact of BIM on complex buildings	1
	More Reliable/Ubiquitous Connectivity and Bandwidth	Smart Market brief BIM advancements	1
	Reduced reliance on paper documents	Smart Market brief BIM advancements, 2013 Information mobility BIM Smart Market	2
	Less Reliance on Blueprints/Specifications	2013 Information mobility BIM Smart Market	
	Better cost control predictability	2014 Business Value of BIM in Global Markets, 2014 The Business Value of BIM for Owners	2
	Use of BIM Has a Beneficial Impact on Control of Construction Costs	2014 The Business Value of BIM for Owners	
	Greater use of integrated design	2010 Green BIM	1
	Modeling for Constructability Evaluation	2014 Business Value of BIM in Global Markets	1
	Generated Better Construction Documents	2015 Measuring the impact of BIM on complex buildings	1

	Reduced construction cost	2014 Business Value of BIM in Global Markets, 2015 Measuring the impact of BIM on complex buildings	2
	Reduced Final Construction Cost of Projects	2015 Measuring the impact of BIM on complex buildings	
	Improved Process and Accuracy of Estimating Construction Costs	2015 Measuring the impact of BIM on complex buildings	1
	Improved Process of Controlling Construction Costs	2015 Measuring the impact of BIM on complex buildings	1
	Percentage Reduction of Final Construction Cost	2015 Measuring the impact of BIM on complex buildings	1
	Improved Ability to Plan Construction Phasing and Logistics	2015 Measuring the impact of BIM on complex buildings	1
	Increased Predictability/Fewer Unplanned Changes	2015 Measuring the impact of BIM on complex buildings	1
	Increased Ability to Manage Project Scope	2015 Measuring the impact of BIM on complex buildings	1
	Improve Building Performance Through BIM-Optimized Facilities Management	2014 Business Value of BIM in Global Markets	1
	Improved Devices for Use at Project Site	Smart Market brief BIM advancements	1
	Improved efficiency of site inspection	Smart Market brief BIM advancements	1
	Reduced Site Labor Due to Increased Offsite Fabrication	2015 Measuring the impact of BIM on complex buildings	1
	Percentage Reduction of Site Labor Due to Increased Offsite Fabrication	2015 Measuring the impact of BIM on complex buildings	1
	Improved Constructability of Final Design	2015 Measuring the impact of BIM on complex buildings	1
	Improved Quality/Function of Final Design	2015 Measuring the impact of BIM on complex buildings	1
	Increased Owners' Ability to Actively Participate in Design Process	2015 Measuring the impact of BIM on complex buildings	1
	Increased Owners' Understanding of Proposed Design Solutions	2015 Measuring the impact of BIM on complex buildings	1
	Improved Owners' Understanding of Construction Phasing and Logistics	2015 Measuring the impact of BIM on complex buildings	1
	Increasing use of BIM for small green retrofit projects	2010 Green BIM	1
	Use a model from the very start to the very end of a project	UK NBIM	1
	Produce a model that did not rely on one piece of software	UK NBIM	1
	Monitoring and verification	2010 Green BIM	1
	Building product material	2010 Green BIM	1
	Creating models with BIM tools	2010 Green BIM	1
	BIM Not Leveraged for Project Meetings	Smart Market brief BIM advancements	1
	Temporary works	Smart Market brief BIM advancements	1

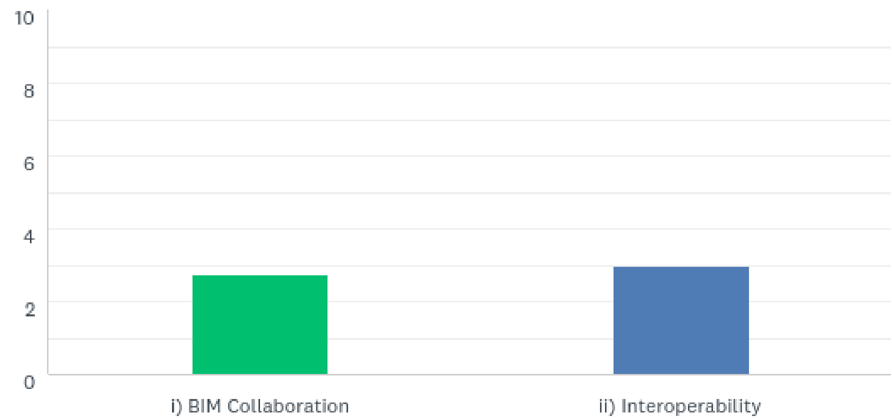
APPENDIX E – RESULTS OF EXPERT REVIEW

1. Do the BIM attributes represent Level 1 - Performed?



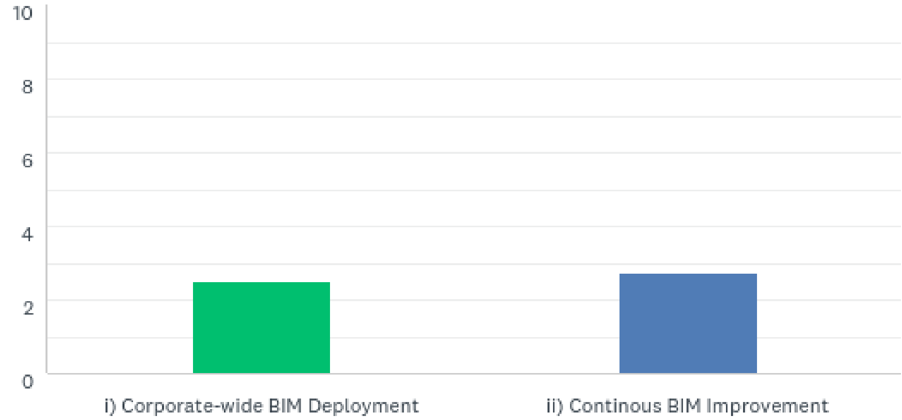
	3-ESSENTIAL	2-IMPORTANT BUT NOT ESSENTIAL	1-NOT ESSENTIAL	TOTAL	WEIGHTED AVERAGE
i) Performing BIM	100.00% 4	0.00% 0	0.00% 0	4	3.00
ii) BIM Training	100.00% 4	0.00% 0	0.00% 0	4	3.00

2. Do the BIM attributes represent Level 2 - Integrated?



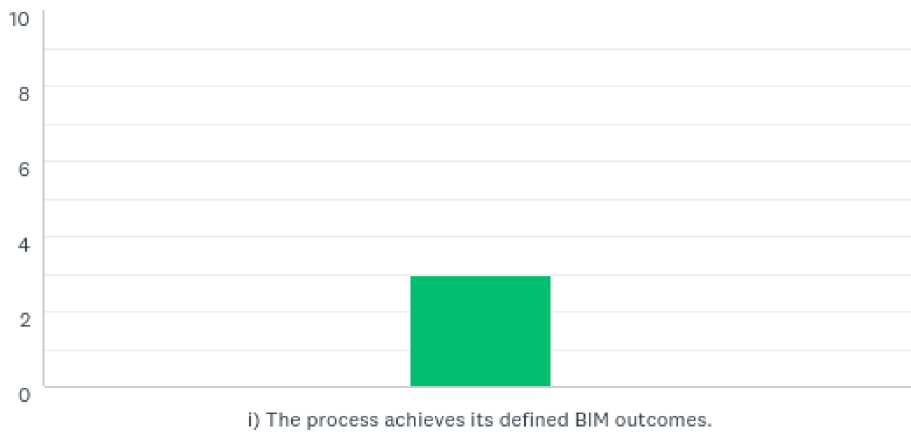
	3-ESSENTIAL	2-IMPORTANT BUT NOT ESSENTIAL	1-NOT ESSENTIAL	TOTAL	WEIGHTED AVERAGE
i) BIM Collaboration	75.00% 3	25.00% 1	0.00% 0	4	2.75
ii) Interoperability	100.00% 4	0.00% 0	0.00% 0	4	3.00

3. Do the BIM attributes represent Level 3 - Optimized?



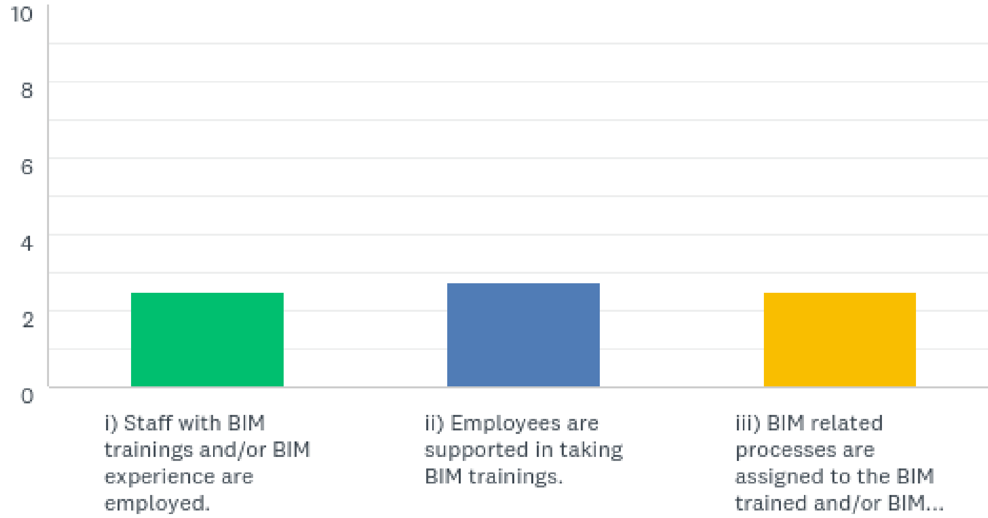
	3-ESSENTIAL	2-IMPORTANT BUT NOT ESSENTIAL	1-NOT ESSENTIAL	TOTAL	WEIGHTED AVERAGE
i) Corporate-wide BIM Deployment	50.00% 2	50.00% 2	0.00% 0	4	2.50
ii) Continous BIM Improvement	75.00% 3	25.00% 1	0.00% 0	4	2.75

4. Does the outcome represent BIM attribute "Performing BIM"?



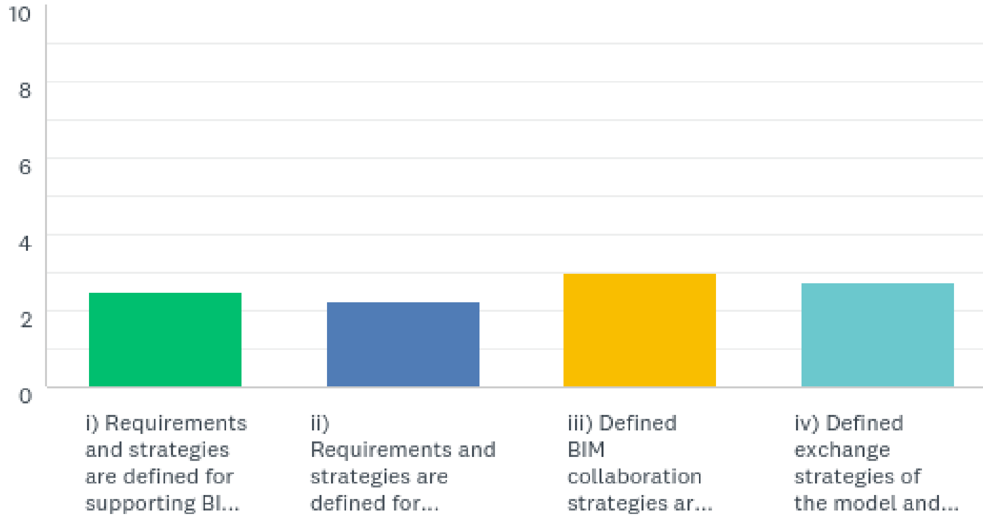
	3-ESSENTIAL	2-IMPORTANT BUT NOT ESSENTIAL	1-NOT ESSENTIAL	TOTAL	WEIGHTED AVERAGE
i) The process achieves its defined BIM outcomes.	100.00% 4	0.00% 0	0.00% 0	4	3.00

5. Do the outcomes represent BIM attribute "BIM Skills"?



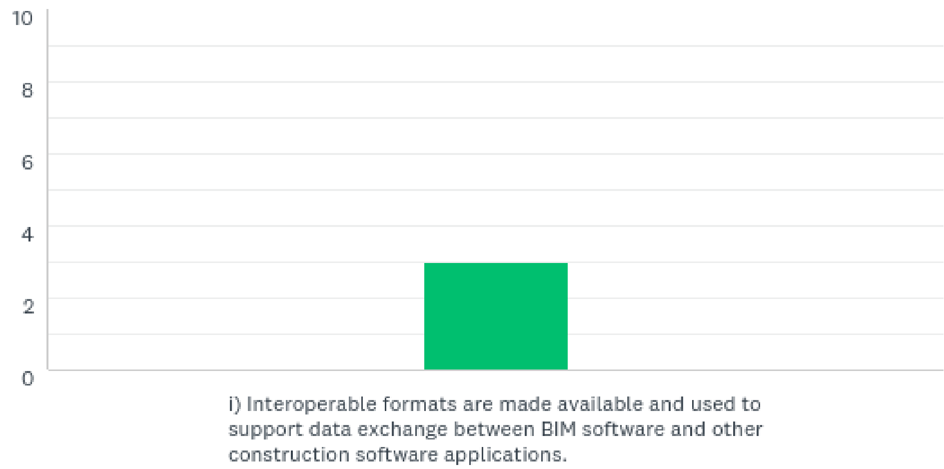
	3-ESSENTIAL	2-IMPORTANT BUT NOT ESSENTIAL	1-NOT ESSENTIAL	TOTAL	WEIGHTED AVERAGE
i) Staff with BIM skills and experience are employed	50.00% 2	50.00% 2	0.00% 0	4	2.50
ii) Employees are supported in taking BIM training.	75.00% 3	25.00% 1	0.00% 0	4	2.75
iii) BIM related processes are assigned to the employees who have BIM skills, experience and has taken BIM trainings.	50.00% 2	50.00% 2	0.00% 0	4	2.50

6. Do the outcomes represent BIM attribute "BIM Collaboration"?



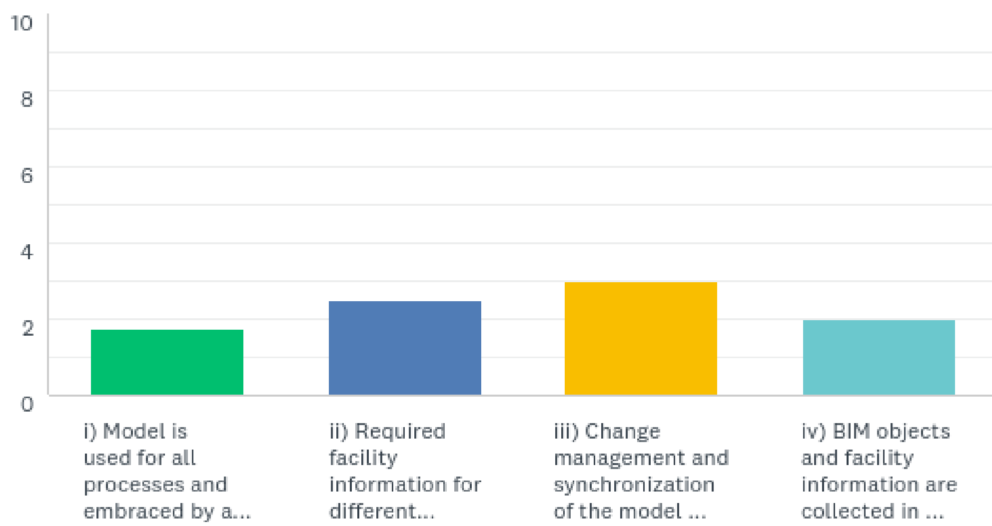
	3-ESSENTIAL	2-IMPORTANT BUT NOT ESSENTIAL	1-NOT ESSENTIAL	TOTAL	WEIGHTED AVERAGE
i) Requirements and strategies are defined for supporting BIM collaboration between internal and external parties.	50.00% 2	50.00% 2	0.00% 0	4	2.50
ii) Requirements and strategies are defined for exchanging the model and the facility information between phases and process.	25.00% 1	75.00% 3	0.00% 0	4	2.25
iii) Defined BIM collaboration strategies are implemented.	100.00% 4	0.00% 0	0.00% 0	4	3.00
iv) Defined exchange strategies of the model and the facility information are implemented.	75.00% 3	25.00% 1	0.00% 0	4	2.75

7. Does the outcome represent BIM attribute "Interoperability"?



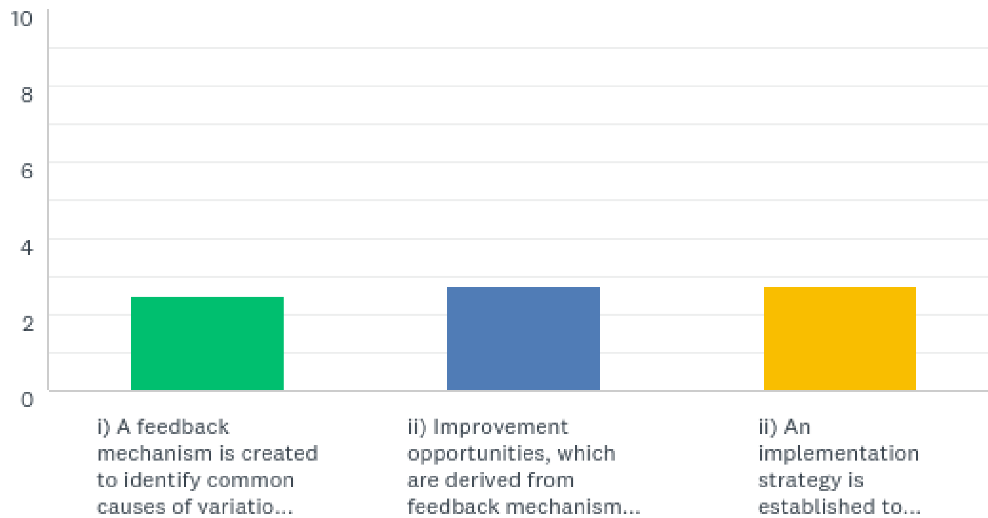
	3-ESSENTIAL	2-IMPORTANT BUT NOT ESSENTIAL	1-NOT ESSENTIAL	TOTAL	WEIGHTED AVERAGE
i) Interoperable formats are made available and used to support data exchange between BIM software and other construction software applications.	100.00% 4	0.00% 0	0.00% 0	4	3.00

8. Do the outcomes represent BIM attribute "Corporate-wide BIM Deployment"?



	3-ESSENTIAL	2-IMPORTANT NOT ESSENTIAL	1-NOT ESSENTIAL	TOTAL	WEIGHTED AVERAGE
i) Model is used for all processes and embraced by all team members.	25.00% 1	25.00% 1	50.00% 2	4	1.75
ii) Required facility information for different processes are extracted from the model and provided for the use of all team members.	50.00% 2	50.00% 2	0.00% 0	4	2.50
iii) Change management and synchronization of the model are performed and the model updates are tracked.	100.00% 4	0.00% 0	0.00% 0	4	3.00
iv) BIM objects and facility information are collected in a library for reusing this information on future projects.	33.33% 1	33.33% 1	33.33% 1	3	2.00

9. Do the outcomes represent BIM attribute "Continuous BIM Improvement"?



	3-ESSENTIAL	2-IMPORTANT BUT NOT ESSENTIAL	1-NOT ESSENTIAL	TOTAL	WEIGHTED AVERAGE
i) A feedback mechanism is created to identify common causes of variations in BIM usage.	75.00% 3	0.00% 0	25.00% 1	4	2.50
ii) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified.	75.00% 3	25.00% 1	0.00% 0	4	2.75
ii) An implementation strategy is established to achieve BIM improvement objectives.	75.00% 3	25.00% 1	0.00% 0	4	2.75

APPENDIX F – CASE STUDY RATINGS

Company A – Conceptual Planning, Architectural, Structural and Building Services Design: Ratings of BIM Outcomes/BIM Attribute Outcomes

BIM Attribute	BIM Outcomes / BIM Attribute Outcomes	Questions	Rating Fully (3) / Largely (2) / Partially (1) / Not Achieved (0)
BIM A 1.1 Performing BIM for P	P2-1. User needs and requirements are defined regarding BIM usage in Design, Construction and FM phases	How do you collect user requirements to be attached for using models in Construction and FM?	3
	P2-2. Existing conditions modelling is conducted for a site/facilities on site/a specific area within a facility	How do you conduct existing conditions modelling?	2
	P3-1. Feasibility information (Economic, environmental and technical) is studied	How do you conduct feasibility studies (economic, environmental and technical)?	0
	P5-1. Define BIM as part of project delivery strategy and identify required BIM services	Do you define BIM as part of project delivery strategy? How do you identify required BIM services?	2
	P5-2. BIM Execution Plan is created	Do you create BEP for each project?	3
	P6-1. Site analysis: Site analysis is conducted to determine the most optimal site location	How do you conduct site analysis?	2
BIM A 1.1 Performing BIM for ARCH D	ARCH D2-1. Draw up space program and requirements are developed (areas, volumes and etc.)	Do you develop draw up program? When do you create it ?	0
	ARCH D2-2.Programming: Design performance is assessed in terms of spatial requirements	How do you assess design performance in terms of spatial requirements?	3
	ARCH D3-1. Design authoring: Architectural design alternatives are created	How do you create architectural design alternatives? Do you use BIM design authoring tools at this stage?	3
	ARCH D3-2. Design authoring: General layout design is developed	How do you create general layout design? Do you use BIM design authoring tools at this stage?	3
	ARCH D3-3. Design authoring: Architectural scheme is created	How do you create ARCH scheme?	3

	ARCH D3-4. Coordination: 3D coordination is conducted between architectural model and models from all disciplines (STR, BS and GEO)	How do you conduct 3D coordination with models from all design disciplines? At what stage of design do you do?	3
	ARCH D3-5. Code validation is performed	Do you perform code validation? Do you use BIM for this purpose?	N/A
	ARCH D3-6.Design authoring: ARCH global model is developed	How do you create architectural global model?	3
	ARCH D3-7. An application for a building permit is submitted	Do you include BIM as part of an application for a building permit?	N/A
	ARCH D4-1. Design review: Design review is conducted for ARCH global model	How do you review the architectural global model?	3
	ARCH D4-2. Design authoring: Detailed architectural model is authored	How do you create detailed architectural model?	3
	ARCH D4-3. Coordination: 3D coordination is conducted between detailed architectural model and all other detailed models (STR, BS, GEO)	How do you conduct 3D coordination?	3
	ARCH D4-4. Design authoring: Architectural detail model is updated further for construction	How do you update the architectural model based on 3D coordination results?	3
	ARCH D4-5. Cost estimating: 5D cost estimating is created via quantity takeoff from the model	How do you get quantity take off from models? How do you prepare cost estimation? At what stage of design do you do?	3
	ARCH D4-6. Phase and 4D planning: 4D planning is prepared to plan construction sequence effectively	Do you prepare phase and 4D planning based on models? At what stage of design do you do?	3
	ARCH D4-7. Engineering analysis: Energy analysis is conducted based on the model to asses building energy performance	How do you do conduct engineering analysis? At what stage of design do you do?	3
	ARCH D4-8. Engineering analysis: Sustainability/LEED evaluation is performed based on the model	How do you evaluate sustainability of buildings? Do you use models? At what stage of design do you do?	0
	ARCH D4-9. Tender documents including BIM protocols are created	Do you include BIM protocols as part of tender documents?	3
	ARCH D5-1. Record modelling: As-Built model is created for use in facility management	Do you update architectural models during construction to create As-Built model? How do you collect As-Built information?	3

BIM A 1.1 Performing BIM for STR D	STR D3-1. Design authoring: Alternative structural frames are developed based on structural possibilities	Do you create structural frames by using BIM authoring tools? How?	3
	STR D3-2. Coordination: 3D Coordination of BS designs and bearing structures, and 3D coordination of STR design alternatives and proposed design solutions for all disciplines (ARCH, BS, GEO) are checked and one STR solution is proposed. for choosing one STR solution	How do you conduct 3D coordination between models from all design disciplines? At what stage of design do you do?	3
	STR D3-3. Coordination: 3D coordination is conducted between chosen STR model and models from all disciplines (ARCH, BS and GEO)	How do you conduct 3D coordination between models from all design disciplines?	3
	STR D3-4. Design authoring: STR model is further authored to create structural global model	Do you update structural models based on 3D coordination results? How do you update?	3
	STR D4-1. Design authoring: Detailed STR model is created based on structural calculations	How do you create structural detail model?	3
	STR D4-2. Engineering analysis: Structural analysis is conducted	How do you conduct structural analysis? At what stage of design do you do?	3
	STR D4-3. Cost estimating: 5D cost estimation is prepared via quantity take off from model	How do you get quantity take off from models? How do you prepare cost estimation?	3
	STR D4-4. Phase and 4D planning: Phase and 4D planning is developed	Do you prepare 4D planning based on models? At what stage of design do you do?	3
	STR D5-1. Record modelling: As-Built model is created for use in facility management	Do you update structural models during construction to create As-Built model? How do you collect As-Built information?	3
BIM A 1.1 Performing BIM for BS D	BS D3-1. Design authoring: Proposed BS models (HVAC, AUT, TEL, ELE) are created	How do you create BS models? Do you use BIM authoring tools at this stage?	3
	BS D3-2. Coordination: 3D coordination is conducted between proposed BS models (HVAC, AUT, TEL, ELE) and proposed models from all disciplines (ARCH, STR, GEO)	How do you conduct 3D coordination between models from all design disciplines? At what stage of design do you do?	3
	BS D3-3. Coordination: 3D coordination is conducted for BS models (HVAC, AUT, TEL, ELE) and BS design solutions are chosen and approved	How do you conduct 3D coordination for all BS models (HVAC, AUT, TEL, ELE)? At what stage of design do you do?	3
	BS D3-4. Design authoring: BS schemes are created and BS global designs are approved	How do you create BS schemes? How do you approve BS schemes?	3

	BS D4-1. Design authoring: Detailed BS models (HVAC, AUT, TEL, ELE) are developed	How do you create detailed BS models?	3
	BS D4-2. Coordination: 3D coordination is conducted between BS detail models (HVAC, AUT, TEL, ELE)	How do you conduct 3D coordination for all BS models (HVAC, AUT, TEL, ELE)?	3
	BS D4-3. Cost estimating: 5D cost estimation is prepared via quantity take off from model	How do you get quantity take off from models? How do you prepare cost estimation?	3
	BS D4-4. Phase and 4D planning: 4D planning is prepared	Do you prepare 4D planning based on models? At what stage of design do you do?	3
	BS D4-5. Engineering analysis: Energy analyses (heating energy consumption, cooling energy consumption, electricity consumption, water consumption, lightening analysis, etc.) are carried	Do you conduct energy analyses based on models? How? At what stage of design do you do?	3
	BS D5-1. Record modelling: As-Built model is created for use in facility management	Do you update the BS models during construction to create As-Built models? How do you collect As-Built information?	3
BIM A 1.2. BIM Skills for P, ARCH, STR, BS D	a) Staff with BIM skills and/or experience are employed	Do you have a strategy for employing staff with BIM skills? Have you ever give any job advertisement to hire a BIM skilled employee?	3
	b) Employees are supported in taking BIM training	How do you support your employees in taking BIM trainings? Do you have a training budget?	3
	c) BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged	How do you decide on assigning the BIM roles and responsibilities to the employees with BIM skills?	2
BIM A 2.1. BIM Collaboration for P, ARCH, STR, BS D	a) Requirements and strategies are defined for supporting BIM collaboration between internal and external parties	Do you have written strategies for collaboration/coordination with internal and external parties? Do you include BIM?	3
	b) Requirements and strategies are defined for exchanging the model and the facility information between phases and processes	Do you have written strategies for exchanging facility information with internal and external parties? Do you include BIM?	3
	c) Defined BIM collaboration strategies are implemented	How do you perform collaboration/coordination with internal and external parties? Do you use BIM? At what stage of design do you do?	3

	d) Defined exchange strategies of the model and the facility information are implemented	How do you exchange facility information between internal and external parties? Do you use BIM?	3
BIM A 2.2 Interoperability for P, ARCH, STR, BS D	a) Interoperable formats are made available and used to support data exchange between BIM software and other construction software applications	Do you use interoperable formats for exchanging models and facility information? Which formats do you use?	3
BIM A 3.1 Corporate-wide BIM Deployment for P, ARCH, STR, BS D	a) Model is used for all processes and embraced by all team members	Do you use models in all of the processes? Is the BIM usage in a process affected by the BIM implementation in another processes? How?	1
	b) Required facility information for different processes are extracted from the model and provided for the use of all team members	Do you have a mechanism for filtering facility information from the model with respect to the user requirements?	1
	c) Change management and synchronization of the model are established and the model updates are tracked	How do you track model revisions? Do you have traceability between model revisions and change requests?	2
	d) BIM objects and facility information are reused on future projects	Do tou have any benchmarks and/or custom 3D object libraries for reusing facility information in future projects?	2
BIM A3.2 Continuous BIM Improvement for P, ARCH, STR, BS D	a) A feedback mechanism is created to identify common causes of variations in BIM usage	Do you have a mechanism for identifiying common problems of BIM leverage? Do you use any tools for identifying the problems?	0
	b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified	How do you derive improvement opportunities to eliminate problems in BIM leverage? Do you have any list of improvement opportunities, reports on industry new technologies and best practices, and etc.?	0
	c) An implementation strategy is established to achieve BIM improvement objectives	How do you implement improvement opportunities to improve BIM usage in the assessed process?	0

Company B - Structural Design for Steel Projects and Reinforced Concrete: Ratings of BIM Outcomes/BIM Attribute Outcomes

BIM Attribute	BIM Outcomes / BIM Attribute Outcomes	Indicator No in Checklist	Assessment Questions	Rating Fully (3) / Largely (2) / Partially (1) / Not Achieved (0)
BIM A 1.1 Performing BIM for STR D of Steel and Reinforced Concrete Frames	STR D3-1. Design authoring: Alternative structural frames are developed based on structural possibilities	1,16,10,12	Do you create structural frames by using BIM authoring tools? How?	3
	STR D3-2. Coordination: 3D Coordination of BS designs and bearing structures, and 3D coordination of STR design alternatives and proposed design solutions for all disciplines (ARCH, BS, GEO) are checked and one STR solution is proposed. for choosing one STR solution	1,2,18,10,11,13	How do you conduct 3D coordination between models from all design disciplines? At what stage of design do you do?	3
	STR D3-3. Coordination: 3D coordination is conducted between chosen STR model and models from all disciplines (ARCH, BS and GEO)	1,2,18,10,11,13	How do you conduct 3D coordination between models from all design disciplines?	3
	STR D3-4. Design authoring: STR model is further authored to create structural global model	1,16,10,12	Do you update structural models based on 3D coordination results? How do you update?	3
	STR D4-1. Design authoring: Detailed STR model is created based on structural calculations	1,16,10,12	How do you create structural detail model?	3
	STR D4-2. Engineering analysis: Structural analysis is conducted	3,5,24,10	How do you conduct structural analysis? At what stage of design do you do?	3
	STR D4-3. Cost estimating: 5D cost estimation is prepared via quantity take off from model	3,5,19,10	How do you get quantity take off from models? How do you prepare cost estimation?	3
	STR D4-4. Phase and 4D planning: Phase and 4D planning is developed	3,4,20,10	Do you prepare 4D planning based on models? At what stage of design do you do?	0
	STR D5-1. Record modelling: As-Built model is created for use in facility management	1,16,10,12	Do you update structural models during construction to create As-built model? How do you collect As-built information?	0

BIM A 1.2. BIM Skills for STR D of Steel and Reinforced Concrete Frames	a) Staff with BIM trainings and/or BIM experience are employed	1,4,6,7	Do you have a strategy for employing staff with BIM skills? Have you ever give any job advertisement to hire a BIM skilled employee?	3
	b) Employees are supported in taking BIM trainings	1,2,8	How do you support your employees in taking BIM trainings? Do you have a training budget?	3
	c) BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged	3,5,9	How do you decide on assigning the BIM roles and responsibilities to the employees with BIM skills?	3
BIM A 2.1. BIM Collaboration for STR D of Steel and Reinforced Concrete Frames	a) Requirements and strategies are defined for supporting BIM collaboration between internal and external parties	1,2,3,4,9,10,11	Do you have written strategies for collaboration/coordination with internal and external parties? Do you include BIM?	3
	b) Requirements and strategies are defined for exchanging the model and the facility information between phases and processes	2,3,5,6,7,8,11	Do you have written strategies for exchanging facility information with internal and external parties? Do you include BIM?	2
	c) Defined BIM collaboration strategies are implemented	1,2,3,4,9,10,11	How do you perform collaboration/coordination with internal and external parties? Do you use BIM? At what stage of design do you do?	3
	d) Defined exchange strategies of the model and the facility information are implemented	2,3,5,6,7,8,11	How do you exchange facility information between internal and external parties? Do you use BIM?	2
BIM A 2.2 Interoperability for STR D of Steel and Reinforced Concrete Frames	a) Interoperable formats are made available and used to support data exchange between BIM software and other construction software applications	1,2,3,4,5	Do you use interoperable formats for exchanging models and facility information? Which formats do you use?	3
BIM A 3.1 Corporate-wide BIM	a) Model is used for all processes and embraced by all team members	1,2,3,7,8,9,10,11	Do you use models in all of the processes? Is the BIM usage in a process	2

Deployment for STR D of Steel Frames			affected by the BIM implementation in another processes? How?	
	b) Required facility information for different processes are extracted from the model and provided for the use of all team members	4,13	Do you have a mechanism for filtering facility information from the model with respect to the user requirements?	1
	c) Change management and synchronization of the model are established and the model updates are tracked	5,11	How do you track model revisions? Do you have traceability between model revisions and change requests?	2
	d) BIM objects and facility information are collected in a library for reusing this information on future projects	1,6,12	Do you have any benchmarks and/or custom 3D object libraries for reusing facility information in future projects?	3
BIM A3.2 Continuous BIM Improvement for STR D of Steel Frames	a) A feedback mechanism is created to identify common causes of variations in BIM usage	1,3	Do you have a mechanism for identifying common problems of BIM leverage? Do you use any tools for identifying the problems?	1
	b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified	2,4,5	How do you derive improvement opportunities to eliminate problems in BIM leverage? Do you have any list of improvement opportunities, reports on industry new technologies and best practices, and etc.?	1
	c) An implementation strategy is established to achieve BIM improvement objectives	1,2,5	How do you implement improvement opportunities to improve BIM usage in the assessed process?	0
BIM A 3.1 Corporate-wide BIM Deployment for STR D of Reinforced	a) Model is used for all processes and embraced by all team members	1,2,3,7,8,9,10,11	Do you the use models in all of the processes? Is the BIM usage in a process affected by the BIM implementation in another processes? How?	0
	b) Required facility information for different processes are extracted from the model and provided for the use of all team members	4,13	Do you have a mechanism for filtering facility information from the model with respect to the user requirements?	1

Concrete Frames	c) Change management and synchronization of the model are established and the model updates are tracked	5,11	How do you track model revisions? Do you have traceability between model revisions and change requests?	2
	d) BIM objects and facility information are collected in a library for reusing this information on future projects	1,6,12	Do you have any benchmarks and/or custom 3D object libraries for reusing facility information in future projects?	3
BIM A3.2 Continuous BIM Improvement for STR D of Reinforced Concrete Frames	a) A feedback mechanism is created to identify common causes of variations in BIM usage	1,3	Do you have a mechanism for identifying common problems of BIM leverage? Do you use any tools for identifying the problems?	1
	b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified	2,4,5	How do you derive improvement opportunities to eliminate problems in BIM leverage? Do you have any list of improvement opportunities, reports on industry new technologies and best practices, and etc.?	1
	c) An implementation strategy is established to achieve BIM improvement objectives	1,2,5	How do you implement improvement opportunities to improve BIM usage in the assessed process?	0

Company C - Architectural Design: Ratings of BIM Outcomes/BIM Attribute Outcomes

BIM Attribute	BIM Outcomes / BIM Attribute Outcomes	Indicator No in Checklist	Questions	Rating Fully (3) / Largely (2) / Partially (1) / Not Achieved (0)
BIM A 1.1 Performing BIM for ARCH D	ARCH D2-1. Draw up space program and requirements are developed (areas, volumes and etc.)	1,5,10	Do you develop draw up program? When do you create it ?	0
	ARCH D2-2.Programming: Design performance is assessed in terms of spatial requirements	1,6,10	How do you assess design performance in terms of spatial requirements?	0
	ARCH D3-1. Design authoring: Architectural design alternatives are created	1,15,10,12	How do you create architectural design alternatives? Do you use BIM design authoring tools at this stage?	3

	ARCH D3-2. Design authoring: General layout design is developed	1,15,10,12	How do you create general layout design? Do you use BIM design authoring tools at this stage?	3
	ARCH D3-3. Design authoring: Architectural scheme is created.	1,15,10,12	How do you create ARCH scheme?	3
	ARCH D3-4. Coordination: 3D coordination is conducted between architectural model and models from all disciplines (STR, BS and GEO)	1,2,18,10,11,13	How do you conduct 3D coordination with models from all design disciplines? At what stage of design do you do?	2
	ARCH D3-5. Code validation is performed	1,3,5,21,1	Do you perform code validation? Do you use BIM for this purpose?	0
	ARCH D3-6.Design authoring: ARCH global model is developed	1,15,10,12	How do you create architectural global model?	3
	ARCH D3-7. An application for a building permit is submitted	1,3,5	Do you include BIM as part of an application for a building permit?	N/A
	ARCH D4-1. Design review: Design review is conducted for ARCH global model	1,15,10,12	How do you review the architectural global model?	3
	ARCH D4-2. Design authoring: Detailed architectural model is authored	1,15,10,12	How do you create detailed architectural model?	3
	ARCH D4-3. Coordination: 3D coordination is conducted between detailed architectural model and all other detailed models (STR, BS, GEO)	1,2,18,10,11,13	How do you conduct 3D coordination?	2
	ARCH D4-4. Design authoring: Architectural detail model is updated further for construction	1,15,10,12	How do you update the architectural model based on 3D coordination results?	3
	ARCH D4-5. Cost estimating: 5D cost estimating is created via quantity take off from the model	3,19,10	How do you get quantity take off from models? How do you prepare cost estimation? At what stage of design do you do?	0
	ARCH D4-6. Phase and 4D planning: 4D planning is prepared to plan construction sequence effectively	3,4,20,10	Do you prepare phase and 4D planning based on models? At what stage of design do you do?	0
	ARCH D4-7. Engineering analysis: Energy analysis is conducted based on the model to asses building energy performance	3,5,24,10	How do you do conduct engineering analysis? At what stage of design do you do?	0
	ARCH D4-8. Engineering analysis: Sustainability (LEED) evaluation is done based on the model	3,5,24,10	How do you evaluate sustainability of buildings? Do you use models? At what stage of design do you do?	0

	ARCH D4-9. Tender documents including BIM protocols are created	5	Do you include BIM protocols as part of tender documents?	N/A
	ARCH D5-1. Record modelling: As-Built model is created for use in facility management	1,15,10,12	Do you update architectural models during construction to create As-Built model? How do you collect As-Built information?	2
BIM A 1.2. BIM Skills for ARCH D	a) Staff with BIM trainings and/or BIM experience are employed	1,4,6,7	Do you have a strategy for employing staff with BIM skills? Have you ever give any job advertisement to hire a BIM skilled employee?	N/A
	b) Employees are supported in taking BIM trainings	1,2,8	How do you support your employees in taking BIM trainings? Do you have a training budget?	N/A
	c) BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged	3,5,9	How do you decide on assigning the BIM roles and responsibilities to the employees with BIM skills?	N/A
BIM A 2.1. BIM Collaboration for ARCH D	a) Requirements and strategies are defined for supporting BIM collaboration between internal and external parties	1,2,3,4,9,10,11	Do you have written strategies for collaboration/coordination with internal and external parties? Do you include BIM?	N/A
	b) Requirements and strategies are defined for exchanging the model and the facility information between phases and processes	2,3,5,6,7,8,11	Do you have written strategies for exchanging facility information with internal and external parties? Do you include BIM?	N/A
	c) Defined BIM collaboration strategies are implemented	1,2,3,4,9,10,11	How do you perform collaboration/coordination with internal and external parties? Do you use BIM? At what stage of design do you do?	N/A
	d) Defined exchange strategies of the model and the facility information are implemented	2,3,5,6,7,8,11	How do you exchange facility information between internal and external parties? Do you use BIM?	N/A
BIM A 2.2 Interoperability for ARCH D	a) Interoperable formats are made available and used to support data exchange between BIM software and other construction software applications	1,2,3,4,5	Do you use interoperable formats for exchanging models and facility information? Which formats do you use?	N/A

BIM A 3.1 Corporate-wide BIM Deployment for ARCH D	a) Model is used for all processes and embraced by all team members	1,2,3,7,8,9,10,11	Do you use models in all of the processes? Is the BIM usage in a process affected by the BIM implementation in another processes? How?	N/A
	b) Required facility information for different processes are extracted from the model and provided for the use of all team members	4,13	Do you have a mechanism for filtering facility information from the model with respect to the user requirements?	N/A
	c) Change management and synchronization of the model are established and the model updates are tracked	5,11	How do you track model revisions? Do you have traceability between model revisions and change requests?	N/A
	d) BIM objects and facility information are collected in a library for reusing this information on future projects	1,6,12	Do you have any benchmarks and/or custom 3D object libraries for reusing facility information in future projects?	N/A
BIM A3.2 Continuous BIM Improvement for ARCH D	a) A feedback mechanism is created to identify common causes of variations in BIM usage	1,3	Do you have a mechanism for identifying common problems of BIM leverage? Do you use any tools for identifying the problems?	N/A
	b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified	2,4,5	How do you derive improvement opportunities to eliminate problems in BIM leverage? Do you have any list of improvement opportunities, reports on industry new technologies and best practices, and etc.?	N/A
	c) An implementation strategy is established to achieve BIM improvement objectives	1,2,5	How do you implement improvement opportunities to improve BIM usage in the assessed process?	N/A

Company D - Construction: Ratings of BIM Outcomes/BIM Attribute Outcomes

BIM Attribute	BIM Outcomes / BIM Attribute Outcomes	Indicator No in Checklist	Assessment Questions	Rating Fully (3) / Largely (2) / Partially (1) / Not Achieved (0)
BIM A 1.1 Performing BIM for C	C1-1. Qualified parties with BIM capability who will be invited to bid on a work package are identified	5	Do you determine qualified parties with required BIM capabilities?	3
	C1-2. Proposals for bid including BIM costs are prepared by qualified parties	5	Do you include BIM costs while creating BIM protocols?	3
	C1-3. Proposals are reviewed and BIM using constructor/subcontractors are selected based on the criteria set by the staffing plan	5	How do you select qualified parties with required BIM capabilities?	3
	C1-4. Contracts including BIM clauses are formalized	5	Do you include BIM clauses in contracts?	3
	C2-1. Phase and 4D planning: Construction sequencing is created	3,4,20,10	Do you prepare phase and 4D planning in construction? How?	3
	C2-2. Site utilization planning: BIM is used to graphically represent facilities on site which can include labor resources, materials with associated deliveries, and equipment location	1,7,10	Do you plan site utilization via BIM? How?	1
	C2-3. 5D cost estimating is used for developing the budget	3,5,19,10	Do you prepare cost estimation at this stage? How do you create?	3
	C2-4. Shop drawings are created using BIM	1,15,10,12	Do you create shop drawings? How?	3
	C2-5. Status/progress monitoring is visualized from site data	8	Do you visualize progress of construction via BIM? How?	3
	C3-1. Resources are acquired and inventory is managed in accordance with inventory information gathered from integrated ERP and BIM tools	5,15,31	How do you acquire resources? How do you manage inventory? Do have linkages between the models and ERP tools?	0
	C3-2. Digital fabrication: Digital fabrication is facilitated	1,12	Do you facilitate digital fabrication from models? How?	1

	C3-3. The distribution priorities are determined based on 4D plan	3, 4,5	Do you determine distribution priorities based on 4D plan?	0
	C4-1.Daily work is executed based on 4D plan	3,4,5,8	Do you conduct daily work in terms of models? How?	3
	C4-2. 3D location identification: Physical locations of elements on site are pinpointed for construction layout	1	Do you identify 3D location of elements for construction layout?	0
	C4-3. Facility is constructed by using BIM	7,8	Do you use model for constructing the facility?	3
	C4-4. Quality assurance is conducted	3,7	Do you conduct quality assurance by using models?	0
	C4-5. Operation data is handed over to the owner with BIM	1,3,4,5	Which facility information is included in handover?	3
BIM A 1.2. BIM Skills for	a) Staff with BIM trainings and/or BIM experience are employed	1,4,6,7	Do you have a strategy for employing staff with BIM skills? Have you ever give any job advertisement to hire a BIM skilled employee?	3
	b) Employees are supported in taking BIM trainings	1,2,8	How do you support your employees in taking BIM trainings? Do you have a training budget?	3
	c) BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged	3,5,9	How do you decide on assigning the BIM roles and responsibilities to the employees with BIM skills?	3
BIM A 2.1. BIM Collaboration for C	a) Requirements and strategies are defined for supporting BIM collaboration between internal and external parties	1,2,3,4,9,10,11	Do you have written strategies for collaboration/coordination with internal and external parties? Do you include BIM?	3
	b) Requirements and strategies are defined for exchanging the model and the facility information between phases and processes	2,3,5,6,7,8,11	Do you have written strategies for exchanging facility information with internal and external parties? Do you include BIM?	3
	c) Defined BIM collaboration strategies are implemented	1,2,3,4,9,10,11	How do you perform collaboration/coordination with internal and external parties? Do you use BIM? At what stage of design do you do?	3
	d) Defined exchange strategies of the model and the facility information are implemented	2,3,5,6,7,8,11	How do you exchange facility information between internal and external parties? Do you use BIM?	3

BIM A 2.2 Interoperability for C	a) Interoperable formats are made available and used to support data exchange between BIM software and other construction software applications	1,2,3,4,5	Do you use interoperable formats for exchanging models and facility information? Which formats do you use?	3
BIM A 3.1 Corporate-wide BIM Deployment for C	a) Model is used for all processes and embraced by all team members	1,2,3,7,8,9,10,11	Do you use models in all of the processes? Is the BIM usage in a process affected by the BIM implementation in another processes? How?	2
	b) Required facility information for different processes are extracted from the model and provided for the use of all team members	4,13	Do you have a mechanism for filtering facility information from the model with respect to the user requirements?	3
	c) Change management and synchronization of the model are established and the model updates are tracked	5,11	How do you track model revisions? Do you have traceability between model revisions and change requests?	3
	d) BIM objects and facility information are collected in a library for reusing this information on future projects	1,6,12	Do you have any benchmarks and/or custom 3D object libraries for reusing facility information in future projects?	4
BIM A3.2 Continuous BIM Improvement for C	a) A feedback mechanism is created to identify common causes of variations in BIM usage	1,3	Do you have a mechanism for identifying common problems of BIM leverage? Do you use any tools for identifying the problems?	2
	b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified	2,4,5	How do you derive improvement opportunities to eliminate problems in BIM leverage? Do you have any list of improvement opportunities, reports on industry new technologies and best practices, and etc.?	2
	c) An implementation strategy is established to achieve BIM improvement objectives	1,2,5	How do you implement improvement opportunities to improve BIM usage in the assessed process?	2

Company E – Design, Construction and Facility Management: Ratings of BIM Outcomes/BIM Attribute Outcomes

BIM Attribute	BIM Outcomes / BIM Attribute Outcomes	Indicator No in Checklist	Questions	Rating Fully (3) / Largely (2) / Partially (1) / Not Achieved (0)
BIM A 1.1 Performing BIM for ARCH D	ARCH D2-1. Draw up space program and requirements are developed (areas, volumes and etc.)	1,5,10	Do you develop draw up program? When do you create it ?	0
	ARCH D2-2. Programming: Design performance is assessed in terms of spatial requirements	1,6,10	How do you assess design performance in terms of spatial requirements?	3
	ARCH D3-1. Design authoring: Architectural design alternatives are created	1,15,10,12	How do you create architectural design alternatives? Do you use BIM design authoring tools at this stage?	3
	ARCH D3-2. Design authoring: General layout design is developed	1,15,10,12	How do you create general layout design? Do you use BIM design authoring tools at this stage?	3
	ARCH D3-3. Design authoring: Architectural scheme is created	1,15,10,12	How do you create ARCH scheme?	3
	ARCH D3-4. Coordination: 3D coordination is conducted between architectural model and models from all disciplines (STR, BS and GEO)	1,2,18,10,11,13	How do you conduct 3D coordination with models from all design disciplines? At what stage of design do you do?	3
	ARCH D3-5. Code validation is performed	1,3,5,21,1	Do you perform code validation? Do you use BIM for this purpose?	0
	ARCH D3-6.Design authoring: ARCH global model is developed	1,15,10,12	How do you create architectural global model?	3
	ARCH D3-7. An application for a building permit is submitted	1,3,5	Do you include BIM as part of an application for a building permit?	N/A
	ARCH D4-1. Design review: Design review is conducted for the global model created	1,15,10,12	How do you review the architectural global model?	3
	ARCH D4-2. Design authoring: Detailed architectural model is authored	1,15,10,12	How do you create detailed architectural model?	3

	ARCH D4-3. Coordination: 3D coordination is conducted between detailed architectural model and all other detailed models (STR, BS, GEO)	1,2,18,10,11,13	How do you conduct 3D coordination?	3
	ARCH D4-4. Design authoring: Architectural detail model is updated further for construction	1,15,10,12	How do you update the architectural model based on 3D coordination results?	3
	ARCH D4-5. Cost estimating: 5D cost estimating is created via quantity take off from the model	3,19,10	How do you get quantity take off from models? How do you prepare cost estimation? At what stage of design do you do?	3
	ARCH D4-6. Phase and 4D planning: 4D planning is prepared to plan construction sequence effectively	3,4,20,10	Do you prepare phase and 4D planning based on models? At what stage of design do you do?	3
	ARCH D4-7. Engineering analysis: Energy analysis is conducted based on the model to asses building energy performance	3,5,24,10	How do you do conduct engineering analysis? At what stage of design do you do?	3
	ARCH D4-8. Engineering analysis: Sustainability (LEED) evaluation is done based on the model	3,5,24,10	How do you evaluate sustainability of buildings? Do you use models? At what stage of design do you do?	2
	ARCH D4-9. Tender documents including BIM protocols are created	5	Do you include BIM protocols as part of tender documents?	3
	ARCH D5-1. Record modelling: As-Built model is created for use in facility management	1,15,10,12	Do you update architectural models during construction to create As-Built model? How do you collect As-built information?	3
BIM A 1.1 Performing BIM for STR D	STR D3-1. Design authoring: Alternative structural frames are developed based on structural possibilities	1,16,10,12	Do you create structural frames by using BIM authoring tools? How?	3
	STR D3-2. Coordination: 3D Coordination of BS designs and bearing structures, and 3D coordination of STR design alternatives and proposed design solutions for all disciplines (ARCH, BS, GEO) are checked and one STR solution is proposed and one STR solution is selected	1,2,18,10,11,13	How do you conduct 3D coordination between models from all design disciplines? At what stage of design do you do?	3

	STR D3-3. Coordination: 3D coordination is conducted between chosen STR model and models from all disciplines (ARCH, BS and GEO)	1,2,18,10,11,13	How do you conduct 3D coordination between models from all design disciplines?	3
	STR D3-4. Design authoring: STR model is further authored to create structural global model	1,16,10,12	Do you update structural models based on 3D coordination results? How do you update?	3
	STR D4-1. Design authoring: Detailed STR model is created based on structural calculations	1,16,10,12	How do you create structural detail model?	3
	STR D4-2. Engineering analysis: Structural analysis is conducted	3,5,24,10	How do you conduct structural analysis? At what stage of design do you do?	3
	STR D4-3. Cost estimating: 5D cost estimation is prepared via quantity take off from model	3,5,19,10	How do you get quantity take off from models? How do you prepare cost estimation?	3
	STR D4-4. Phase and 4D planning: Phase and 4D planning is developed	3,4,20,10	Do you prepare 4D planning based on models? At what stage of design do you do?	3
	STR D5-1. Record modelling: As-Built model is created for use in facility management	1,16,10,12	Do you update structural models during construction to create As-Built model? How do you collect As-built information?	3
BIM A 1.1 Performing BIM for BS D	BS D3-1. Design authoring: Proposed BS models (HVAC, AUT, TEL, ELE) are created	1,17,10,12	How do you create BS models? Do you use BIM authoring tools at this stage?	3
	BS D3-2. Coordination: 3D coordination is conducted between proposed BS models (HVAC, AUT, TEL, ELE) and proposed models from all disciplines (ARCH, STR, GEO)	2,18,10,11,13	How do you conduct 3D coordination between models from all design disciplines? At what stage of design do you do?	3
	BS D3-3. Coordination: 3D coordination is conducted for BS models (HVAC, AUT, TEL, ELE) and BS design solutions are chosen and approved	2,18,10,11,13	How do you conduct 3D coordination for all BS models (HVAC, AUT, TEL, ELE)? At what stage of design do you do?	3
	BS D3-4. Design authoring: BS schemes are created and BS global designs are approved	1,17,10,12	How do you create BS schemes? How do you approve BS schemes?	3

	BS D4-1. Design authoring: Detailed BS models (HVAC, AUT, TEL, ELE) are developed	1,17,10,12	How do you create detailed BS models?	3
	BS D4-2. Coordination: 3D coordination is conducted between BS detail models (HVAC, AUT, TEL, ELE)	2,18,10,11,13	How do you conduct 3D coordination for all BS models (HVAC, AUT, TEL, ELE)?	3
	BS D4-3. Cost estimating: 5D cost estimation is prepared via quantity take off from model	3,5,19,10	How do you get quantity take off from models? How do you prepare cost estimation?	3
	BS D4-4. Phase and 4D planning: 4D planning is prepared	3,4,20,10	Do you prepare 4D planning based on models? At what stage of design do you do?	3
	BS D4-5. Engineering analysis: Energy analyses (heating energy consumption, cooling energy consumption, electricity consumption, water consumption, lightening analysis, etc.) are carried	3,5,24,10	Do you conduct energy analyses based on models? How? At what stage of design do you do?	3
	BS D5-1. Record modelling: As-Built model is created for use in facility management	1,17,10,12	Do you update the BS models during construction to create As-Built models? How do you collect As-built information?	3
BIM A 1.1 Performing BIM for C	C1-1. Qualified parties with BIM capability who will be invited to bid on a work package are identified	5	Do you determine qualified parties with required BIM capabilities?	3
	C1-2. Proposals for bid including BIM costs are prepared by qualified parties	5	Do you include BIM costs while creating BIM protocols?	3
	C1-3. Proposals are reviewed and BIM using constructor/subcontractors are selected based on the criteria set by the staffing plan	5	How do you select qualified parties with required BIM capabilities?	3
	C1-4. Contracts including BIM clauses are formalized	5	Do you include BIM clauses in contracts?	3
	C2-1. Phase and 4D planning: Construction sequencing is created	3,4,20,10	Do you prepare phase and 4D planning in construction? How?	3
	C2-2. Site utilization planning: BIM is used to graphically represent facilities on site which can include labor resources, materials with associated deliveries, and equipment location	1,7,10	Do you plan site utilization via BIM? How?	3

	C2-3. 5D cost estimating is used for developing the budget	3,5,19,10	Do you prepare cost estimation at this stage? How do you create?	3
	C2-4. Shop drawings are created using BIM	1,15,10,12	Do you create shop drawings? How?	3
	C2-5. Status/progress monitoring is visualized from site data	8	Do you visualize progress of construction via BIM? How?	3
	C3-1. Resources are acquired and inventory is managed in accordance with inventory information gathered from integrated ERP and BIM tools	5,15,31	How do you acquire resources? How do you manage inventory? Do have linkages between the models and ERP tools?	0
	C3-2. Digital fabrication: Digital fabrication is facilitated	1,12	Do you facilitate digital fabrication from models? How?	2
	C3-3. The distribution priorities are determined based on 4D plan	3, 4,5	Do you determine distribution priorities based on 4D plan?	3
	C4-1. Daily work is executed based on 4D plan	3,4,5,8	Do you conduct daily work in terms of models? How?	3
	C4-2. 3D location identification: Physical locations of elements on site are pinpointed for construction layout	1	Do you identify 3D location of elements for construction layout?	3
	C4-3. Facility is constructed by using BIM	7,8	Do you use model for constructing the facility?	3
	C4-4. Quality assurance is conducted	3,7	Do you conduct quality assurance by using models?	3
	C4-5. Operation data is handed over to the owner with BIM	1,3,4,5	Which facility information is included in handover?	3
BIM A 1.1 Performing BIM for FM	FM1-1. Asset management: Financial decision making, short term and long term planning and generating work orders schedules are assisted via integrating record models with asset management systems	1,5,7,27	Do you define BIM as part of asset management plans? How do you make cost decisions regarding to assets by using BIM? Do have links between models and asset management tools?	3
	FM1-2.Space management: Scape distribution, management and tracking is utilized by integrating record models and spatial tracking software	1,5,7,32	Do you define BIM as part of space management plans? How do you track space distribution? Do you have links between models and space management tools?	3

	FM1-3. Disaster planning and management: Critical building information is made available to the responders by integrating record models and BMS which allows clear display of emergency locations	1,5,7,8,10,28,33	Do you define BIM as part of disaster plans? How do you monitor real data and make available to responders?	0
	FM2-1. Physical performance information and operations historical data reviewed via integrating record models and facility management systems	1,2,26,27,28	where do you store operations data? Do you review physical performance information and historical data by using model?	3
	FM2-2. O&M scheduling is planned by integrating record models and facility management systems such as BAS and CMMS	1,26,27,28	How do you create O&M schedules? Do you have links between models and facility management tools?	3
	FM3-1. Facility points/areas are selected for collecting operations data through sensors	1,10,28	Do you consider BIM while selecting facility points/areas? Are the selected locations installed into the model?	0
	FM3-2. Operations data, which is collected through sensors, is stored, classified, or simplified in record model integrated with BAS in order to be used by other functions	1,2,8,10,28	How do you store, classify collected data for monitoring?	0
	FM4-1. Monitoring information for identifying problem area is compared with critical or expected performance values which are attached to models	1,2,9	Do you attach expected performance values/elements' manuals to the model?	0
	FM5-1. Root-cause analysis is performed by using the model to understand the problem	1,2,26,27,28	Do you conduct root-cause analysis by using the model?	3
	FM5-2. Technical solution for the problem is designed by using the model	1,5,28	How do you design the technical solution for the problem? Do you include BIM?	2
	FM5-3. Implications of the problem solving plan are analyzed by using the model	1,5,28	Do you use BIM for analyzing implications of the problem solving plan?	2
	FM6-1. Decisions for selecting problem solution plan are made via integrating models and facility management tools/asset management tools	1,5,26,27	How do you make decisions for selecting the problem solution plan?	0
	FM6-2. Services and resources for implementing the plan are allocated by integrating models and facility management tools	1,5,26,27	How do you allocate required services and resources for implementing the plan?	0

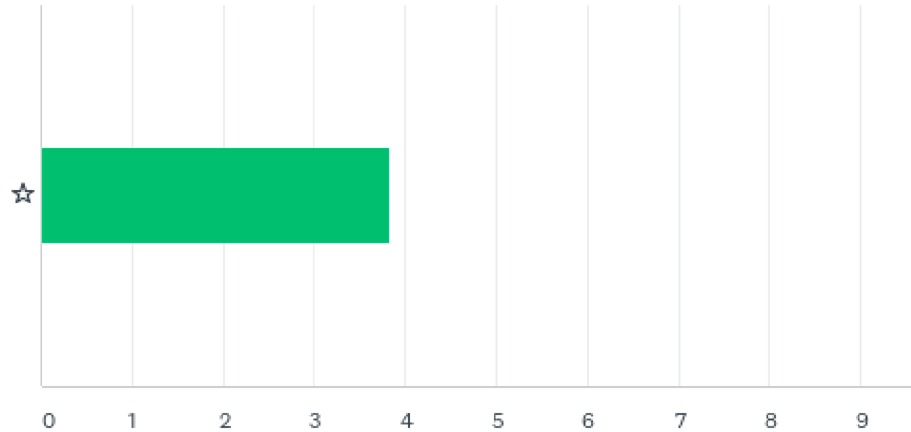
	FM7-1. Performed O&M tasks are reflected to the model	1	Do you add O&M data to the model?	3
BIM A 1.2. BIM Skills for ARCH D, STR D, BS D, C, FM	a) Staff with BIM trainings and/or BIM experience are employed	1,4,6,7	Do you have a strategy for employing staff with BIM skills? Have you ever give any job advertisement to hire a BIM skilled employee?	3
	b) Employees are supported in taking BIM trainings	1,2,8	How do you support your employees in taking BIM trainings? Do you have a training budget?	3
	c) BIM related processes are assigned to the BIM trained and/or BIM experienced employees or peer learning is encouraged	3,5,9	How do you decide on assigning the BIM roles and responsibilities to the employees with BIM skills?	1
BIM A 2.1. BIM Collaboration for ARCH D, STR D, BS D, C, FM	a) Requirements and strategies are defined for supporting BIM collaboration between internal and external parties	1,2,3,4,9,10,11	Do you have written strategies for collaboration/coordination with internal and external parties? Do you include BIM?	3
	b) Requirements and strategies are defined for exchanging the model and the facility information between phases and processes	2,3,5,6,7,8,11	Do you have written strategies for exchanging facility information with internal and external parties? Do you include BIM?	3
	c) Defined BIM collaboration strategies are implemented	1,2,3,4,9,10,11	How do you perform collaboration/coordination with internal and external parties? Do you use BIM? At what stage of design do you do?	3
	d) Defined exchange strategies of the model and the facility information are implemented	2,3,5,6,7,8,11	How do you exchange facility information between internal and external parties? Do you use BIM?	3
BIM A 2.2 Interoperability for ARCH D, STR D, BS D, C, FM	a) Interoperable formats are made available and used to support data exchange between BIM software and other construction software applications	1,2,3,4,5	Do you use interoperable formats for exchanging models and facility information? Which formats do you use?	3

BIM A 3.1 Corporate-wide BIM Deployment for ARCH D, STR D, BS D, C	a) Model is used for all processes and embraced by all team members	1,2,3,7,8,9,10,11	Do you use models in all of the processes? Is the BIM usage in a process affected by the BIM implementation in another processes? How?	3
	b) Required facility information for different processes are extracted from the model and provided for the use of all team members	4,13	Do you have a mechanism for filtering facility information from the model with respect to the user requirements?	3
	c) Change management and synchronization of the model are established and the model updates are tracked	5,11	How do you track model revisions? Do you have traceability between model revisions and change requests?	3
	d) BIM objects and facility information are collected in a library for reusing this information on future projects	1,6,12	Do you have any benchmarks and/or custom 3D object libraries for reusing facility information in future projects?	3
BIM A3.2 Continuous BIM Improvement for ARCH D, STR D, BS D, C	a) A feedback mechanism is created to identify common causes of variations in BIM usage	1,3	Do you have a mechanism for identifying common problems of BIM leverage? Do you use any tools for identifying the problems?	2
	b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified	2,4,5	How do you derive improvement opportunities to eliminate problems in BIM leverage? Do you have any list of improvement opportunities, reports on industry new technologies and best practices, and etc.?	3
	c) An implementation strategy is established to achieve BIM improvement objectives	1,2,5	How do you implement improvement opportunities to improve BIM usage in the assessed process?	2
BIM A 3.1 Corporate-wide BIM Deployment for FM	a) Model is used for all processes and embraced by all team members	1,2,3,7,8,9,10,11	Do you use models in all of the processes? Is the BIM usage in a process affected by the BIM implementation in another processes? How?	2
	b) Required facility information for different processes are extracted from the model and provided for the use of all team members	4,13	Do you have a mechanism for filtering facility information from the model with respect to the user requirements?	2

	c) Change management and synchronization of the model are established and the model updates are tracked	5,11	How do you track model revisions? Do you have traceability between model revisions and change requests?	2
	d) BIM objects and facility information are collected in a library for reusing this information on future projects	1,6,12	Do you have any benchmarks and/or custom 3D object libraries for reusing facility information in future projects?	3
BIM A3.2 Continuous BIM Improvement for FM	a) A feedback mechanism is created to identify common causes of variations in BIM usage	1,3	Do you have a mechanism for identifying common problems of BIM leverage? Do you use any tools for identifying the problems?	2
	b) Improvement opportunities, which are derived from feedback mechanism and from new BIM technology trends and best practices, are identified	2,4,5	How do you derive improvement opportunities to eliminate problems in BIM leverage? Do you have any list of improvement opportunities, reports on industry new technologies and best practices, and etc.?	3
	c) An implementation strategy is established to achieve BIM improvement objectives	1,2,5	How do you implement improvement opportunities to improve BIM usage in the assessed process?	2

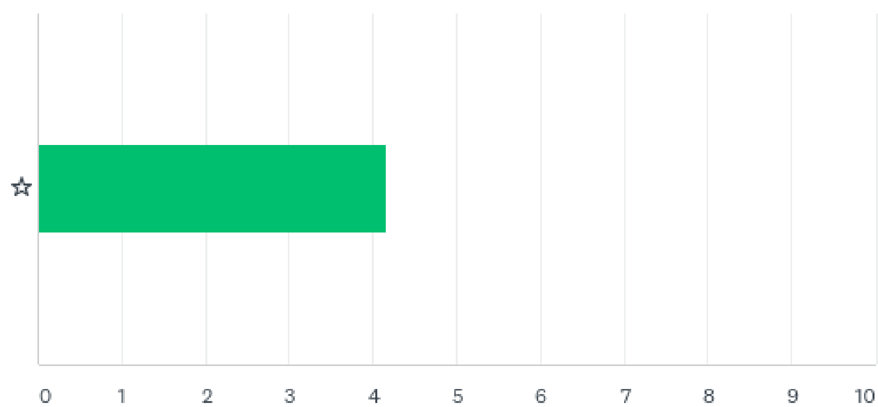
APPENDIX G – VALIDATION OF MULTIPLE CASE STUDY

1. BIM-CAREM is capable of identifying the BIM capabilities of AEC/FM processes.



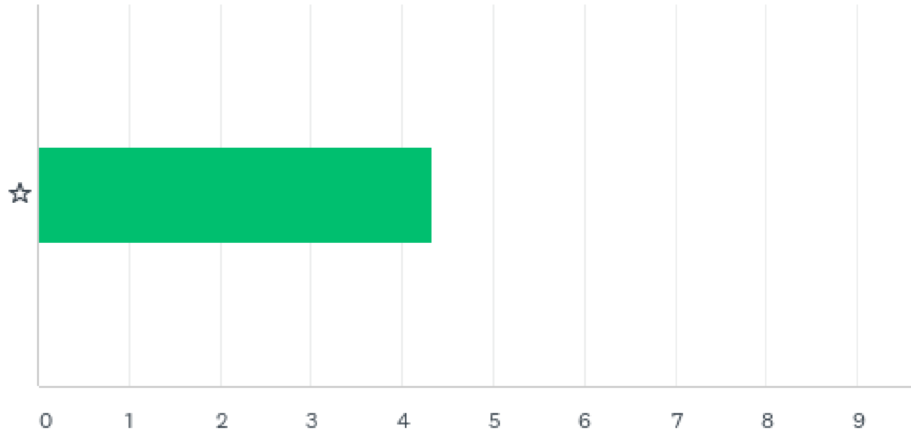
	STRONGLY DISAGREE (KESINLIKLE KATILMIYORUM)	DISAGREE (KATILMIYORUM)	NEUTRAL (NÖTR)	AGREE (KATILIYORUM)	STRONGLY AGREE (KESINLIKLE KATILIYORUM)	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	16.67% 1	83.33% 5	0.00% 0	6	3.83

2. BIM-CAREM can be utilized for identifying BIM capabilities of AEC/FM organizations' processes.



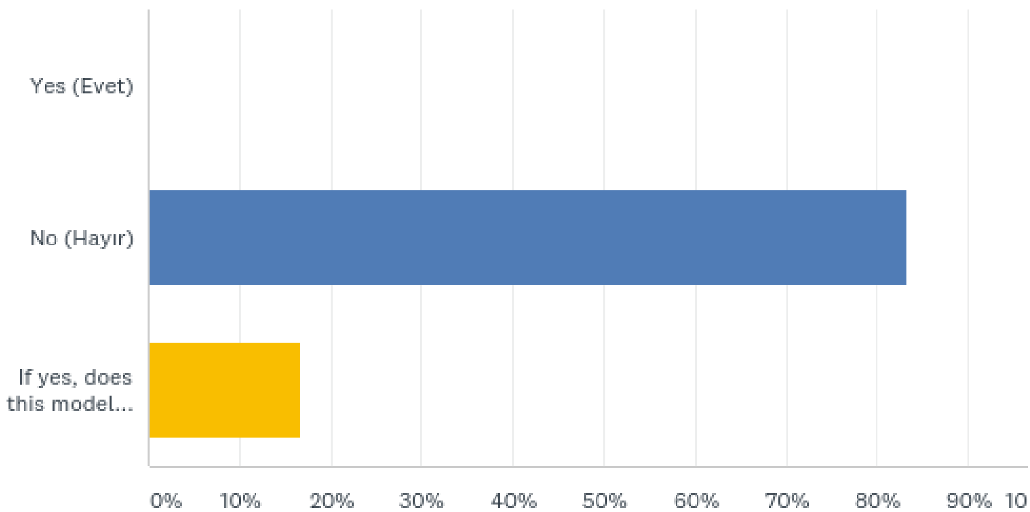
	STRONGLY DISAGREE (KESINLIKLE KATILMIYORUM)	DISAGREE (KATILMIYORUM)	NEUTRAL (NÖTR)	AGREE (KATILIYORUM)	STRONGLY AGREE (KESINLIKLE KATILIYORUM)	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	16.67% 1	50.00% 3	33.33% 2	6	4.17

3. BIM-CAREM is helpful to understand the BIM related gaps of AEC/FM processes by identifying their BIM capabilities.



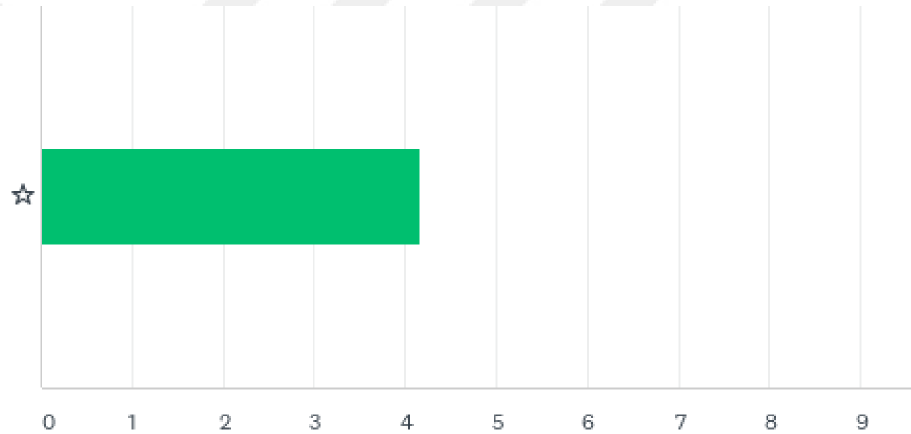
	STRONGLY DISAGREE (KESINLIKLE KATILMIYORUM)	DISAGREE (KATILMIYORUM)	NEUTRAL (NÖTR)	AGREE (KATILIYORUM)	STRONGLY AGREE (KESINLIKLE KATILIYORUM)	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	0.00% 0	66.67% 4	33.33% 2	6	4.33

4. Have you ever experienced such a model before?



ANSWER CHOICES	RESPONSES	
Yes (Evet)	0.00%	0
No (Hayır)	83.33%	5
If yes, does this model create better results than the alternatives? Pelase elaborate your comments?Eğer evetse, sizce bu model alternatiflerden daha iyi sonuçlar veriyor mu?	16.67%	1
TOTAL		6

5. To what extent do the assessment results match with the BIM capability which you thought before?



	STRONGLY MISMATCH (KESINLIKLE EŞLEŞMIYOR)	MISMATCH (EŞLEŞMIYOR)	NEUTRAL (NÖTR)	MATCH (EŞLEŞIYOR)	STRONGLY MATCH (KESINLIKLE EŞLEŞIYOR)	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	0.00% 0	83.33% 5	16.67% 1	6	4.17

APPENDIX H – CHECKLISTS OF COMPANIES

Company B - Structural Design for Steel Projects and Reinforced Concrete

BIM Capability Level 1-Performed BIM			
BIM A 1.1 Performing BIM			
Generic BIM Work Products			
Indicator No	**Work Product/Resource**	**Example**	**Exists or not? (Y/N)**
1	Models including parametric intelligence	Models, As-Built models, models including facility information	Y
2	Structured Data	Point clouds, 3D coordination viewpoints, sensor data	Y
3	Reports/Sheets	Feasibility reports, clash detection reports, quantity takeoffs, time lines for phase and 4D planning, construction sequencing, quality assurance reports, maintenance schedules	Y
4	Simulations	Phase and 4D planning simulation	N
5	Reports/Documents	BEPs, engineering analysis reports	Y
6	Calculations	Design performance calculations	Y
7	Model views	Model views for different users' purposes	N
8	Real-time data	Progress monitoring data	N
9	Manuals	Equipment manuals attached to models	N
Generic Resources			
10	Hardware/Devices	Powerful workstations, servers, tablets, wireless handheld devices	Y
11	Network	WLAN, LAN	Y
12	Security services	Security services for ownership of models	Y
13	Services	Cloud storage services	Y
14	Databases	Object libraries, point cloud databases	Y
15	Architectural BIM authoring tools	ArchiCAD, Bentley Architecture, Digital Project, Revit	N
16	Structural BIM authoring tools	Revit Structures, Tekla Structures	Y
17	MEP BIM authoring tools	CAD Duct, CAD MEP, Revit MEP	N

18	3D coordination tool	Navisworks, Newforma	Y
19	Cost estimating tool	DProfiler, Sage Timberline, Navisworks, Revit	Y
20	Scheduling tool	Primavera, Strategic Project Solutions, Vico Control, Synchro	N
21	Rule-checking software	Solibri	N
22	Survey control tool	Trimble RealWorks	N
23	Laser scanning tool	Cloudworx	N
24	Energy analysis tool	TraneTrace, EnergyPlus	N
25	Structural analysis tool	RAM, Robot Millenium, Strand, ETABS, SAP	Y
26	Computer aided facility management tools	ARCHIBUS, Trimble Centerstone	N
27	Computerized maintenance management system/Asset management tools	IBM Maximo	N
28	Building automation system	Building automation systems	N
29	Virtual reality services	Mixed reality, augmented reality	N
30	Location services	GPS	N
31	Non-construction software	Procurement, ERP	Y
32	Space management tools	Trimble CenterStone	N
33	Indoor mapping solutions	Trimble Indoor Mobile Mapping Solution	N
		BIM A 1.2 BIM Skills	
		Generic BIM Work Products	
1	Employees	Employees with BIM experience and/or who have taken BIM trainings	Y
2	BIM training records	BIM consultancy records, seminar/training records, BIM competition records	N
3	BIM roles	Organization scheme	Y
4	Advertisements	BIM job advertisements	N
5	Reports	Strategies for assigning BIM roles	Y
		Generic Resources	
6	Employees	Employees with BIM skills and/or certifications	Y
7	BIM experts	BIM consultant, BIM expert	Y
8	Annual budget	BIM training budget	N

Indicator No	Work product/Resources	Example	Exists or not? (Y/N)
9	Standards	National, international standards about BIM trainings	Y
		BIM Capability Level 2-Intgerated BIM	
		BIM A 2.1 BIM Collaboration	
		Generic BIM Work Products	
Indicator No	**Work product/Resources**	**Example**	**Exists or not? (Y/N)**
1	Models	Shared models for coordination	Y
2	BEP	BIM vision, BIM uses, project deliverables and BIM deliverables	Y
3	Documents/reports	BIM collaboration strategies and facility information exchange procedures	Y
4	Collaboration meetings	BIM coordination rooms, meeting minutes	Y
5	Standard formats	File and folder structures on common data environments and/or shared servers, naming conventions of files, model formats for different stages such as NC	Y
6	Sheets	Information delivery manuals, COBie	N
		Generic Resources	
7	International standards	National BIM guide, PAS 1192, AEC BIM protocol, COBie, IDM	N
8	Hardware	Common data environments, shared servers, cloud storage	Y
9	BIM collaboration software	Autodesk BIM 360 Team, Autodesk Collaboration for Revit	N
10	Construction document management tools	Autodesk BIM 360 docs, Aconex	Y
11	Services	Cloud storage services	Y
		BIM A 2.2 Interoperability	
		Generic BIM Work Products	
1	Models represented by interoperable formats	Models in different formats such as IFC, XML, NC	Y
2	Direct links for model sharing	Models with direct and proprietary links	Y
		Generic Resources	
3	Interoperable formats	XML, IFC	Y
4	Direct and proprietary links	ArchiCad’s GDL, Revit’s Open API, Bentley’s MD	Y

Indicator No	Work Product/Resource	Example	Exists or not? (Y/N)
5	Plugins	Plugins for specific BIM tools	Y
		BIM Capability Level 3-Optimized BIM	
		BIM A 3.1 Corporate-wide BIM Deployment	
		Generic BIM Work Products	
Indicator No	**Work Product/Resource**	**Example**	**Exists or not? (Y/N)**
1	Same model used in all processes	Fabrication from models, progress payment from models	Y
2	Company-wide BEPs	Defined BIM uses within company	Y
3	Integration of BIM tools with non-construction software applications	Linkages between BIM tools and ERPs	N
4	Model views for different processes	Different views of models	N
5	Documents/reports	Strategies for change requests, revisions of models, linkages between change requests and model revisions	Y
6	Benchmarks, libraries	3D object libraries, benchmarks including facility information and project information	Y
		Generic Resources	
7	Software	Autodesk BIM 360 Team	N
8	Multi-user BIM tools	Update notifications, synchronization of model versions	Y
9	Virtual reality services	Mixed reality, augmented reality	N
10	Hardware	Tablets, wireless hand held devices, sensors	N
11	Cloud storage services	Autodesk Vault	Y
12	BIM server	Autodesk collaborative project management	N
13	International standards	Model View Definitions	N
		BIM A 3.2 Continuous BIM Improvement	
		Generic BIM Work Products	
1	Documents/reports	BIM goals and strategies, procedures for identifying problems of BIM usage, BIM improvement objectives	N
2	Meetings	Innovation meetings, meeting minutes	Y
		Generic Resources	
3	Software	Data analytics tools	N

4	Technical reports/publications	Membership for technical reviews	Y
5	Employees	Higher level management support	Y

Company C - Architectural Design

BIM Capability Level 1-Performed BIM			
BIM A 1.1 Performing BIM			
Generic BIM Work Products			
Indicator No	**Work Product/Resource**	**Example**	**Exists or not? (Y/N)**
1	Models including parametric intelligence	Models, As-Built models, models including facility information	Y
2	Structured Data	Point clouds, 3D coordination viewpoints, sensor data	N
3	Reports/Sheets	Feasibility reports, clash detection reports, quantity takeoffs, time lines for phase and 4D planning, construction sequencing, quality assurance reports, maintenance schedules	N
4	Simulations	Phase and 4D planning simulation	N
5	Reports/Documents	BEPs, engineering analysis reports	Y
6	Calculations	Design performance calculations	N
7	Model views	Model views for different users' purposes	N
8	Real-time data	Progress monitoring data	N
9	Manuals	Equipment manuals attached to models	N
Generic Resources			
10	Hardware/Devices	Powerful workstations, servers, tablets, wireless handheld devices	Y
11	Network	WLAN, LAN	Y
12	Security services	Security services for ownership of models	Y
13	Services	Cloud storage services	Y
14	Databases	Object libraries, point cloud databases	N
15	Architectural BIM authoring tools	ArchiCAD, Bentley Architecture, Digital Project, Revit	Y
16	Structural BIM authoring tools	Revit Structures, Tekla Structures	N

17	MEP BIM authoring tools	CAD Duct, CAD MEP, Revit MEP	N
18	3D coordination tool	Navisworks, Newforma	Y
19	Cost estimating tool	DProfiler, Sage Timberline, Navisworks, Revit	N
20	Scheduling tool	Primavera, Strategic Project Solutions, Vico Control, Synchro	N
21	Rule-checking software	Solibri	N
22	Survey control tool	Trimble RealWorks	N
23	Laser scanning tool	Cloudworx	N
24	Energy analysis tool	TraneTrace, EnergyPlus	N
25	Structural analysis tool	RAM, Robot Millenium, Strand, ETABS, SAP	N
26	Computer aided facility management tools	ARCHIBUS, Trimble Centerstone	N
27	Computerized maintenance management system/Asset management tools	IBM Maximo	N
28	Building automation system	Building automation systems	N
29	Virtual reality services	Mixed reality, augmented reality	N
30	Location services	GPS	N
31	Non-construction software	Procurement, ERP	N
32	Space management tools	Trimble CenterStone	N
33	Indoor mapping solutions	Trimble Indoor Mobile Mapping Solution	N
		BIM A 1.2 BIM Skills	
		Generic BIM Work Products	
1	Employees	Employees with BIM experience and/or who have taken BIM trainings	Y
2	BIM training records	BIM consultancy records, seminar/training records, BIM competition records	N
3	BIM roles	Organization scheme	N
4	Advertisements	BIM job advertisements	N
5	Reports	Strategies for assigning BIM roles	N
		Generic Resources	
6	Employees	Employees with BIM skills and/or certifications	Y
7	BIM experts	BIM consultant, BIM expert	N

8	Annual budget	BIM training budget	N
9	Standards	National, international standards about BIM trainings	N

Company D - Construction

Indicator No	Work Product/Resource	Example	Exists or not? (Y/N)
		BIM Capability Level 1-Performed BIM	
		BIM A 1.1 Performing BIM	
		Generic BIM Work Products	
1	Models including parametric intelligence	Models, As-Built models, models including facility information	Y
2	Structured Data	Point clouds, 3D coordination viewpoints, sensor data	Y
3	Reports/Sheets	Feasibility reports, clash detection reports, quantity takeoffs, time lines for phase and 4D planning, construction sequencing, quality assurance reports, maintenance schedules	Y
4	Simulations	Phase and 4D planning simulation	Y
5	Reports/Documents	BEPs, engineering analysis reports	Y
6	Calculations	Design performance calculations	Y
7	Model views	Model views for different users' purposes	N
8	Real-time data	Progress monitoring data	Y
9	Manuals	Equipment manuals attached to models	N
		Generic Resources	
10	Hardware/Devices	Powerful workstations, servers, tablets, wireless handheld devices	Y
11	Network	WLAN, LAN	Y
12	Security services	Security services for ownership of models	Y
13	Services	Cloud storage services	Y
14	Databases	Object libraries, point cloud databases	Y
15	Architectural BIM authoring tools	ArchiCAD, Bentley Architecture, Digital Project, Revit	Y
16	Structural BIM authoring tools	Revit Structures, Tekla Structures	Y
17	MEP BIM authoring tools	CAD Duct, CAD MEP, Revit MEP	Y
18	3D coordination tool	Navisworks, Newforma	Y
19	Cost estimating tool	DProfiler, Sage Timberline, Navisworks, Revit	Y
20	Scheduling tool	Primavera, Strategic Project Solutions, Vico Control, Synchro	Y

21	Rule-checking software	Solibri	N
22	Survey control tool	Trimble RealWorks	Y
23	Laser scanning tool	Cloudworx	Y
24	Energy analysis tool	TraneTrace, EnergyPlus	N
25	Structural analysis tool	RAM, Robot Millenium, Strand, ETABS, SAP	Y
26	Computer aided facility management tools	ARCHIBUS, Trimble Centerstone	N
27	Computerized maintenance management system/Asset management tools	IBM Maximo	N
28	Building automation system	Building automation systems	N
29	Virtual reality services	Mixed reality, augmented reality	Y
30	Location services	GPS	Y
31	Non-construction software	Procurement, ERP	Y
32	Space management tools	Trimble CenterStone	N
33	Indoor mapping solutions	Trimble Indoor Mobile Mapping Solution	N
		BIM A 1.2 BIM Skills	
		Generic BIM Work Products	
1	Employees	Employees with BIM experience and/or who have taken BIM trainings	Y
2	BIM training records	BIM consultancy records, seminar/training records, BIM competition records	Y
3	BIM roles	Organization scheme	Y
4	Advertisements	BIM job advertisements	Y
5	Reports	Strategies for assigning BIM roles	Y
		Generic Resources	
6	Employees	Employees with BIM skills and/or certifications	
7	BIM experts	BIM consultant, BIM expert	Y
8	Annual budget	BIM training budget	Y
9	Standards	National, international standards about BIM trainings	Y
		BIM Capability Level 2-Intgerated BIM	
		BIM A 2.1 BIM Collaboration	
		Generic BIM Work Products	
Indicator No	**Work product/Resources**	**Example**	**Exists or not? (Y/N)**
1	Models	Shared models for coordination	Y
2	BEP	BIM vision, BIM uses, project deliverables and BIM deliverables	N

3	Documents/reports	BIM collaboration strategies and facility information exchange procedures	Y
4	Collaboration meetings	BIM coordination rooms, meeting minutes	Y
5	Standard formats	File and folder structures on common data environments and/or shared servers, naming conventions of files, model formats for different stages such as NC	Y
6	Sheets	Information delivery manuals, COBie	N
		Generic Resources	
7	International standards	National BIM guide, PAS 1192, AEC BIM protocol, COBie, IDM	N
8	Hardware	Common data environments, shared servers, cloud storage	Y
9	BIM collaboration software	Autodesk BIM 360 Team, Autodesk Collaboration for Revit	Y
10	Construction document management tools	Autodesk BIM 360 docs, Aconex	Y
11	Services	Cloud storage services	Y
		BIM A 2.2 Interoperability	
		Generic BIM Work Products	
1	Models represented by interoperable formats	Models in different formats such as IFC, XML, NC	Y
2	Direct links for model sharing	Models with direct and proprietary links	Y
		Generic Resources	
3	Interoperable formats	XML, IFC	Y
4	Direct and proprietary links	ArchiCad's GDL, Revit's Open API, Bentley's MD	Y
5	Plugins	Plugins for specific BIM tools	Y
		BIM Capability Level 3-Optimized BIM	
		BIM A 3.1 Corporate-wide BIM Deployment	
		Generic BIM Work Products	
Indicator No	**Work Product/Resource**	**Example**	**Exists or not? (Y/N)**
1	Same model used in all processes	Fabrication from models, progress payment from models	Y
2	Company-wide BEPs	Defined BIM uses within company	Y
3	Integration of BIM tools with non-construction software applications	Linkages between BIM tools and ERPs	N
4	Model views for different processes	Different views of models	Y

5	Documents/reports	Strategies for change requests, revisions of models, linkages between change requests and model revisions	Y
6	Benchmarks, libraries	3D object libraries, benchmarks including facility information and project information	Y
		Generic Resources	
7	Software	Autodesk BIM 360 Team	Y
8	Multi-user BIM tools	Update notifications, synchronization of model versions	Y
9	Virtual reality services	Mixed reality, augmented reality	Y
10	Hardware	Tablets, wireless hand held devices, sensors	Y
11	Cloud storage services	Autodesk Vault	Y
12	BIM server	Autodesk collaborative project management	N
13	International standards	Model View Definitions	N
		BIM A 3.2 Continuous BIM Improvement	
		Generic BIM Work Products	
1	Documents/reports	BIM goals and strategies, procedures for identifying problems of BIM usage, BIM improvement objectives	Y
2	Meetings	Innovation meetings, meeting minutes	Y
		Generic Resources	
3	Software	Data analytics tools	N
4	Technical reports/publications	Membership for technical reviews	Y
5	Employees	Higher level management support	Y

Company E – Design, Construction and Facility Management

		BIM Capability Level 1-Performed BIM	
		BIM A 1.1 Performing BIM	
		Generic BIM Work Products	
Indicator No	**Work Product/Resource**	**Example**	**Exists or not? (Y/N)**
1	Models including parametric intelligence	Models, As-Built models, models including facility information	Y
2	Structured Data	Point clouds, 3D coordination viewpoints, sensor data	Y

3	Reports/Sheets	Feasibility reports, clash detection reports, quantity takeoffs, time lines for phase and 4D planning, construction sequencing, quality assurance reports, maintenance schedules	Y
4	Simulations	Phase and 4D planning simulation	Y
5	Reports/Documents	BEPs, engineering analysis reports	Y
6	Calculations	Design performance calculations	Y
7	Model views	Model views for different users' purposes	Y
8	Real-time data	Progress monitoring data	Y
9	Manuals	Equipment manuals attached to models	N
		Generic Resources	
10	Hardware/Devices	Powerful workstations, servers, tablets, wireless handheld devices	Y
11	Network	WLAN, LAN	Y
12	Security services	Security services for ownership of models	Y
13	Services	Cloud storage services	Y
14	Databases	Object libraries, point cloud databases	Y
15	Architectural BIM authoring tools	ArchiCAD, Bentley Architecture, Digital Project, Revit	Y
16	Structural BIM authoring tools	Revit Structures, Tekla Structures	Y
17	MEP BIM authoring tools	CAD Duct, CAD MEP, Revit MEP	Y
18	3D coordination tool	Navisworks, Newforma	Y
19	Cost estimating tool	DProfiler, Sage Timberline, Navisworks, Revit	Y
20	Scheduling tool	Primavera, Strategic Project Solutions, Vico Control, Synchro	Y
21	Rule-checking software	Solibri	Y
22	Survey control tool	Trimble RealWorks	Y
23	Laser scanning tool	Cloudworx	Y
24	Energy analysis tool	TraneTrace, EnergyPlus	Y
25	Structural analysis tool	RAM, Robot Millenium, Strand, ETABS, SAP	Y
26	Computer aided facility management tools	ARCHIBUS, Trimble Centerstone	Y
27	Computerized maintenance management system/Asset management tools	IBM Maximo	Y
28	Building automation system	Building automation systems	Y
29	Virtual reality services	Mixed reality, augmented reality	Y
30	Location services	GPS	Y
31	Non-construction software	Procurement, ERP	Y
32	Space management tools	Trimble CenterStone	Y

33	Indoor mapping solutions	Trimble Indoor Mobile Mapping Solution	N
		BIM A 1.2 BIM Skills	
		Generic BIM Work Products	
1	Employees	Employees with BIM experience and/or who have taken BIM trainings	Y
2	BIM training records	BIM consultancy records, seminar/training records, BIM competition records	Y
3	BIM roles	Organization scheme	Y
4	Advertisements	BIM job advertisements	Y
5	Reports	Strategies for assigning BIM roles	Y
		Generic Resources	
6	Employees	Employees with BIM skills and/or certifications	
7	BIM experts	BIM consultant, BIM expert	Y
8	Annual budget	BIM training budget	Y
9	Standards	National, international standards about BIM trainings	Y
		BIM Capability Level 2-Intgerated BIM	
		BIM A 2.1 BIM Collaboration	
		Generic BIM Work Products	
Indicator No	**Work product/Resources**	**Example**	**Exists or not? (Y/N)**
1	Models	Shared models for coordination	Y
2	BEP	BIM vision, BIM uses, project deliverables and BIM deliverables	Y
3	Documents/reports	BIM collaboration strategies and facility information exchange procedures	Y
4	Collaboration meetings	BIM coordination rooms, meeting minutes	Y
5	Standard formats	File and folder structures on common data environments and/or shared servers, naming conventions of files, model formats for different stages such as NC	Y
6	Sheets	Information delivery manuals, COBie	N
		Generic Resources	
7	International standards	National BIM guide, PAS 1192, AEC BIM protocol, COBie, IDM	Y
8	Hardware	Common data environments, shared servers, cloud storage	Y
9	BIM collaboration software	Autodesk BIM 360 Team, Autodesk Collaboration for Revit	Y
10	Construction document management tools	Autodesk BIM 360 docs, Aconex	Y

11	Services	Cloud storage services	Y
	BIM A 2.2 Interoperability		
	Generic BIM Work Products		
1	Models represented by interoperable formats	Models in different formats such as IFC, XML, NC	Y
2	Direct links for model sharing	Models with direct and proprietary links	Y
	Generic Resources		
3	Interoperable formats	XML, IFC	Y
4	Direct and proprietary links	ArchiCad's GDL, Revit's Open API, Bentley's MD	Y
5	Plugins	Plugins for specific BIM tools	Y
	BIM Capability Level 3-Optimized BIM		
	BIM A 3.1 Corporate-wide BIM Deployment		
	Generic BIM Work Products		
Indicator No	**Work Product/Resource**	**Example**	**Exists or not? (Y/N)**
1	Same model used in all processes	Fabrication from models, progress payment from models	Y
2	Company-wide BEPs	Defined BIM uses within company	Y
3	Integration of BIM tools with non-construction software applications	Linkages between BIM tools and ERPs	N
4	Model views for different processes	Different views of models	N
5	Documents/reports	Strategies for change requests, revisions of models, linkages between change requests and model revisions	Y
6	Benchmarks, libraries	3D object libraries, benchmarks including facility information and project information	Y
	Generic Resources		
7	Software	Autodesk BIM 360 Team	Y
8	Multi-user BIM tools	Update notifications, synchronization of model versions	Y
9	Virtual reality services	Mixed reality, augmented reality	Y
10	Hardware	Tablets, wireless hand held devices, sensors	Y
11	Cloud storage services	Autodesk Vault	Y
12	BIM server	Autodesk collaborative project management	N
13	International standards	Model View Definitions	Y
	BIM A 3.2 Continuous BIM Improvement		
	Generic BIM Work Products		

1	Documents/reports	BIM goals and strategies, procedures for identifying problems of BIM usage, BIM improvement objectives	Y
2	Meetings	Innovation meetings, meeting minutes	Y
		Generic Resources	
3	Software	Data analytics tools	Y
4	Technical reports/publications	Membership for technical reviews	Y
5	Employees	Higher level management support	Y

APPENDIX I – CURRICULUM VITAE

Address: Middle East Technical University, Informatics Institute, 06800, Ankara, Turkey

E-Mail: gokcenyilmaz@gmail.com

Education

2012 – 2017

PhD in Information Systems, Middle East Technical University (METU), CGPA: **3.75/4.00**

BIM-CAREM: A reference model for Building Information Modelling (BIM) capability assessments, Supervisors: Assist. Prof Aslı Akçamete Güngör and Prof Onur Demirörs

- Conducted extensive literature review on **Building Information Modelling (BIM),**
- Created **building reference model** which includes a list of key building processes (40 building processes) and defined each of them,
- Created **measurement framework** to use for measuring BIM capabilities of the defined processes,
- Observed a formal appraisal of **ISO/IEC 15504 – Software Process Improvement and Capability Determination** in a software company in İzmir,
- Validated BIM-CAREM through **expert reviews** and **an exploratory case study,**
- Conducted formal appraisals by using BIM-CAREM and tested it through **multiple case studies in four different Turkish construction firms** (design of metro lines, structural design of stadiums, industrial facilities, construction of hospitals, design and construction of buildings and airports, and facilities management of airports).

2009 – 2012

MSc in Information Systems, METU, CGPA: **3.13/4.00**

An automated defect detection approach for COSMIC functional size measurement method, Supervisor: Prof Onur Demirörs

- Implemented **R-COVER**: a software measurement verification module which enables automatic verification of COSMIC functional size measurements,
- Identified most **commonly made user errors** by analysing various different COSMIC functional size measurements reports and **patterns of these errors**,
- Developed a **defect detection approaches** based on the patterns,
- Created **detection algorithms** and implemented those algorithms in **Java** and created **R-COVER**,
- Tested R-COVER with different **test cases** in which new measurement reports are fed into the tool and defects are identified automatically,
- Observed improvement in the accuracy of COSMIC functional size measurements.

2003 – 2008 **BS in Industrial and Systems Engineering**, Yeditepe University, CGPA: **3.20/4.00**

- Simulated the supply chain of the company, which produces ignition systems for ovens by using STELLA.

Research Experience

2014 – 2015 **Visiting Researcher** at **Distributed Information and Automation Laboratory (DIAL), IfM, the University of Cambridge** and **Centre for Smart Infrastructure and Construction (CSIC)**

Information futureproofing for large-scale infrastructure

- Involved in development of the **Information futureproofing approach/tool** which helps users to identify facility information retention requirements for long term use and to calculate likelihood of information loss,
- Conducted literature review from both **construction** and **non-construction domains** for determining criteria for **keeping facility information long term**,
- Conducted **semi-structured interviews** with construction organizations such as **Crossrail and London Underground** for identifying **hazards** which may cause **facility information loss**,
- Carried out a **case study in facility management stage of the university buildings,** which are operated by Estate Management Division of the University of Cambridge.

2009 – 2017 **Research Assistant** at **METU**

Researcher, Software benchmarking and functional size measurement, funded by The Scientific and Technological Research Council of Turkey

- Implemented **R-COVER** which is the software measurement verification module of **CUBIT** (is a web based software application to measure software projects, store benchmark and measurement data and analyse it in the future) by using Java programming language,
- Involved in creation of user guides and related software documents (functional software requirements specification document including use cases, Software design document, etc.) of CUBIT.

Researcher, Turkish translation of COSMIC Functional Size Measurement Method

- Involved in translation of Measurement Manual, COSMIC Implementation, Guide for ISO/IEC 19761: V3.0.1

Publications

- **Yilmaz, G**, Akcamete, A and Demirors, O (**2017**). “A Review on Capability and Maturity Models of Building Information Modelling” Lean and Computing in Construction Congress (LC3), Crete, 4-10 July 2017.

- Masood, T, **Yilmaz, G**, McFarlane, DC and Parlikad, AK (**2016**). "Long-term data preservation and access: infrastructure assets perspective", Our Digital Future - Multidisciplinary Perspectives on Long Term Data Preservation and Access, 15-16 March 2016.
- Masood, T, **Yilmaz, G**, McFarlane, DC, Parlikad, AK, Harwood, K and Dunn, R (**2016**). "Information future-proofing assessment for infrastructure assets" Proceedings of International Conference of Smart Infrastructure & Construction, Cambridge, 27-29 June 2016.
- **Yilmaz, G**, Masood, T and McFarlane, DC (**2015**). "Identifying and validating hazards in support of information future-proofing – case study of a building", IET/IAM Conference on Asset Management, London, 25-26 November 2015.
- Woodall, P, **Yilmaz, G**, Giannikas, V, Lu, W, McFarlane, D (**2015**). "New directions for warehousing data management research: Extensions to an existing review", IEEE 13th International Conference on Industrial Informatics (INDIN), pg. 610-613, 2015.
- Ertugrul, M, **Yilmaz, G**, Salmanoglu, M, Demirors, O (**2014**). "The Effect of Highlighting Error Categories in FSM Training on the Accuracy of Measurement", International Workshop on Software Measurement and International Conference on Software Process and Product Measurement, 2014.
- **Yilmaz, G.**, Tunalilar, S., Demirors, O (**2013**)."Towards the Development of a Defect Detection Tool for COSMIC Functional Size Measurement", 23rd International Workshop on Software Measurement and International Conference on Software Process and Product Measurement, Ankara, 23-26 Oct. 2013
- **Yilmaz, G**, Ungan, E, Demirors, O (**2011**) "The Effect of the Quality of Software Requirements Document on the Functional Size Measurements," UKSMA, London, 2011.

Scholarships and Awards

2003 – 2008	Full scholarship for BSc Education, the Council of Higher Education.
2014 – 2015	TUBITAK 2214/A - Research Fellowship Program for PhD Students, the Scientific and Technological Research Council of Turkey.
2014 – 2016	R&D and Innovation Program, Ministry of Science, Industry and Technology.
2013 – 2014	Entrepreneurship multi-phase program, Ministry of Science, Industry and Technology.

Key Research Skills

Qualitative

- Multiple case studies, In-depth interviews

Quantitative

- Statistical analysis with SPSS

Construction Management

- BIM capability and maturity models, BIM performance measurement approaches and metrics
- Industry Foundation Classes
- Hands on experience about how to combine an open source facility management tool with BIM

- National BIM Standard-United States (NBIMS), PAS 1192 (part 1,2,3,4 and 5) and Construction Operation Building information exchange (COBie)

Software Engineering

- Abbotts Method, Design patterns, UML
- Software project management (created Software Requirements Specification, Software Design Document, Software Project Management Plan)
- Software process assessment and improvement (ISO/IEC 330xx family of standards and ISO/IEC 15504 –Software Process Improvement and Capability Determination, Capability and Maturity Model Integration)

Programming languages and Tools

- Java, C/C++, Eclipse, Visual Studio, SQL Server, Joomla, Drupal 7

Entrepreneurship

- Lean start up, Business development, Business model canvas, Minimum viable product.

Teaching Experience

2009 – 2017

Teaching Assistant of the courses Introduction to **Software Testing, Personal Software Process and Software Requirements Engineering** in different semesters

- Responsible for grading assignments, answering students' questions, bridging the gap between students and the main instructor

Instructor of the course **Introduction to Information Technologies and Applications (IS100)** for two semesters

- Instructing the course at the undergraduate level
- Syllabus can be found at: https://ii.metu.edu.tr/is100-syllabus

Coordinator of the course **IS100**

- Preparing course exams, homework and updating the announcements
- Coordinating course assistants during each term and controlling their coursework and grading
- Updated the content of the course in terms of new technologies

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Professional Experience

2013 – Present

Co-founder at Gökçağ Yazılım, Middle East Technical University Techno Park, Responsible for business development and sales

- An android based NFC mobile payment system and smart campus application are offered,
- Pilot product, which has android wallet system, management system as a desktop application, and a communication system for reader, is developed.

2008 – 2009

Production Planning Engineer at Amaç Electronics, Istanbul

- Preparing daily production plan and tracking raw material warehouse.

July 2008	**Warehouse Intern** at Omsan Logistics, Istanbul

- Tested the new Warehouse Management System.

Certifications

October 2017 — nVIDIA Deep Learning Institute, Deep Leaning Fundamentals Workshop at Graduate School of Informatics, METU

- Image classification with DIGITS
- Object detection with DIGITS
- Neural network deployment with DIGITS and TensorRT

February 2011 — Certified COSMIC functional size measurer by COSMIC organization, UK and Canada. (https://cosmic-sizing.org/certification/taking-exam/)

Referees

Assist. Prof Aslı Akçamete Güngör at Civil Enigineering, METU. Email: akcamete@metu.edu.tr

Prof Onur Demirörs at Computer Engineering, Izmir Institute of Technology and Senior visiting fellow at School of Computer Science and Engineering, The University of New South Wales. Email: demirorso@gmail.com

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