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GRADUATE SCHOOL OF NATURAL  
AND APPLIED SCIENCES**

**ENHANCED PROJECT DELIVERY FROM  
CONSTRUCTION TO OPERATIONS AND BIM USE IN  
FACILITY MANAGEMENT: ISTANBUL AIRPORT  
CASE STUDY**

**MASTER'S DEGREE THESIS IN  
CIVIL ENGINEERING  
CONSTRUCTION MANAGEMENT**

**BY**

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**JANUARY 2021**

**Enhanced Project Delivery From Construction to  
Operations And BIM Use In Facility Management: Istanbul  
Airport Case Study**

**Hasan Kalyoncu University  
Civil Engineering Faculty  
Master's Degree Thesis**

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January 2021**



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## ABSTRACT

### ENHANCED PROJECT DELIVERY FROM CONSTRUCTION TO OPERATIONS AND BIM USE IN FACILITY MANAGEMENT: ISTANBUL AIRPORT CASE STUDY

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BIM can be defined as a management methodology developed to increase productivity and add value in construction projects and at every stage of the project life cycle. In addition to the planning, design and construction stages in the project life cycle, the use of BIM in facility management offers significant opportunities to increase the efficiency of asset management, energy management and other operational processes. Using BIM for facility management requires successful implementation and integration throughout the project. The areas of use, potential benefits and the process management methodologies required for the successful implementation of digital twin models in which graphical and non-graphical data of assets are represented in virtual environment for facility management are the subjects of this thesis. The Istanbul Airport case study, where the BIM application can be seen from the beginning to the end within the scope of the thesis, reveals important data in this sense.

**Key Words:** Building Information Modelling, Facility Management, Project Delivery, Project Handover

## ÖZET

### BİM İLE İNŞAATTAN İŞLETMEYE GELİŞTİRİLMİŞ PROJE TESLİMİ VE TESİS YÖNETİMİ: İSTANBUL HAVALİMANI VAKA ÇALIŞMASI

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89 sayfa

BİM, inşaat projelerinde ve proje yaşam döngüsünün her aşamasında verimliliği artırmaya ve değer katmaya yönelik geliştirilen bir yönetim metodolojisi olarak tanımlanabilir. Proje yaşam döngüsünde planlama, tasarım ve inşaat aşamalarının yanında tesis yönetiminde BİM kullanımı, varlık yönetimi, enerji yönetimi ve diğer operasyonel süreçlerin verimliliğinin artırılmasında önemli fırsatlar sunmaktadır. Tesis yönetimi için BİM kullanımı proje boyunca başarılı bir uygulama ve entegrasyon gerektirmektedir. Tesis yönetimi için varlıkların grafiksel ve grafiksel olmayan verilerinin sanal ortamda temsil edildiği dijital ikiz modellerinin kullanım alanları, potansiyel faydaları ve başarıyla uygulanabilmesi için gereken süreç yönetim metodolojilerinin incelenmesi ve ortaya konması bu tezin konusudur. Tez kapsamında başından sonuna BİM uygulamasının görülebileceği İstanbul Havalimanı vaka çalışması bu anlamda önemli veriler ortaya koymaktadır.

**Anahtar Kelimeler:** Yapı Bilgi Modellemesi, Tesis Yönetimi, Proje Teslimi, Dijital İkiz

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January 2021

Simge VURĞUN ÇELİKEL

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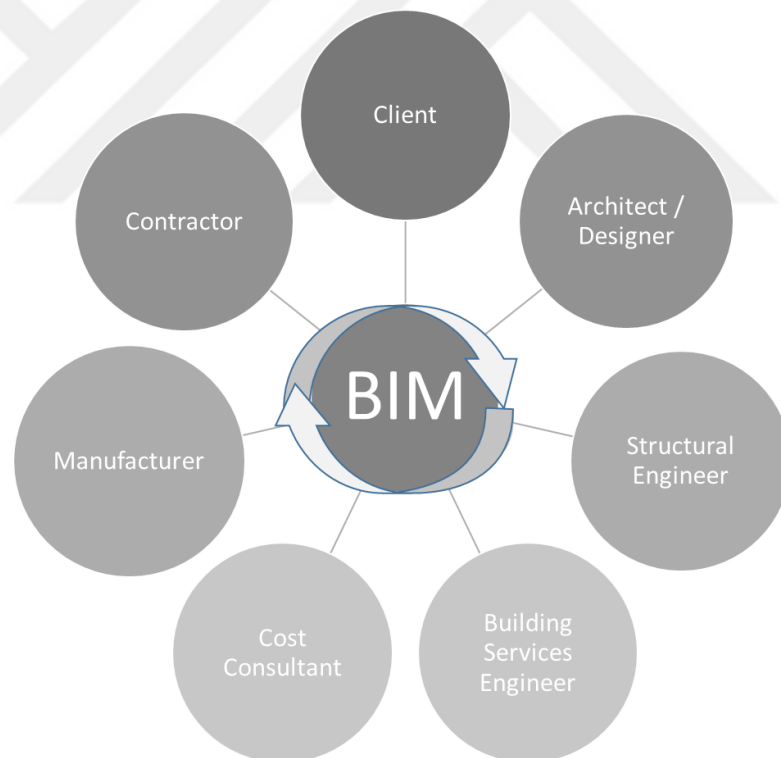
## LIST OF ABBREVIATIONS

AEC	Architecture, Engineering and Construction
AHU	Air Handling Unit
APM	Air Passenger Movement
ATC	Air Traffic Control
BAS	Building Automation System
BHS	Baggage Handling System
BIM	Building Information Management
BMS	Building Management System
CAD	Computer Aided Design
CMMS	Computerized Maintenance Management System
CAFM	Computer-aided Facility Management
EPC	Engineering, Procurement, Construction
ERP	Enterprise Resource Plannig
GBS	Green Building Studio
GIS	Geographic Information System
HVAC	Heating Ventilating and Air Conditioning
IFC	Issued for Construction
IWMS	Integratd Workplace Management System
LOD	Level of Development/Detail
MAF	Material Approval Form
MEP	Mechanical, Electrical and Plumbing
MS	Method of Statement
NFI	Notification for Inspection
O/O	Owner / Operator
O&M	Operations and Maintenance
QA/QC	Quality Assurance/Quality Control
RFI	Request for Information
T&C	Test and Commisioning
TCR	Test and Commisioning Request

## CHAPTER 1

### INTRODUCTION

Building Information Modeling (BIM) concept contains the most promising technologies in the sectors of architecture, engineering and construction (AEC). The advantages it provides make many companies want to incorporate and use BIM in their complex projects. This purpose, however, is not very easy to put into practice because of the subject's creativity and because of the great complexity that implies moving from conventional processes to BIM (Eastman, et al., 2011). All participating parties in AEC industry is involved in BIM processes (Figure 1).



**Figure 1.** BIM (Building Information Modelling) Participating Parties in AEC Industry

Digital technology for the definition and display of information needed in the planning , design , construction and operation of built installations is supported by building information modeling. This modeling methodology is increasingly expanding, from

civil infrastructure, services and public space, to cover all aspects of the built environment. These are collectively referred to as construction procedures. This approach to knowledge management puts together the various collections of records used during the designed environment's life cycle into a single database environment, reducing and even removing the need for the many types of paper documentation already in use (International Organization for Standardization, 2016).

BIM is a master, intelligent data model, resulting in an as-built database that can be conveniently supplied upon completion of commissioning to the building operator. With the implementation of BIM, CAD data with product descriptions, submissions, shop drawings, project records, as-built documents and details on operations can be combined in a single multi-dimensional platform which makes conventionally written O&M and system manuals obsolete. The smart buildings of tomorrow are supposed to require the complex interaction of design and information systems. In order to maintain an optimal environment, building materials and systems can sense internal and external conditions, predict changes, and automatically make necessary adjustments. (National Institute of Building Sciences, 2016)

For various daytime exposures, space lighting would be changed and window control systems would adapt automatically, such as blinds, louvers, environmentally reactive glass. To track efficiency and possible degradation over time, wireless sensors will be installed in building envelope materials, and then give facility managers early warning of potential issues.

### **1.1. Background of the Research**

The construction sector has seen extreme changes in the use of IT over the last decades. (Fisher et al. 2006). BIM contains the most promising example of development in construction sector (Eastman et al. 2011). BIM can be defined as a mechanism that allows data and domain information to be stored and reused during the project life cycle. (Vanlande and Nicolle 2008). Therefore, organizing the exchange of information and knowledge between all other disciplines and all stages of the project is a central and critical task for BIM.

In a construction project, the use of BIM has both the possible advantage of enhancing product efficiency and the introduction of more sustainable building design (Eastman et al. 2011).

Even though BIM's financial and environmental advantages are generally recognized (Eastman et al. 2011), The implementation of this new technology was sluggish (Bernstein and Pittman 2005).

BIM is more commonly known in the construction industry because it interacts with great visualization and planning in a software that can be easily reached by each discipline. The construction industry has been faced with a paradigm change to increase efficiency, infrastructure value, quality and sustainability and to reduce costs and reworks by effective coordination and collaboration where the construction managers faces a considerable amount of difficulty to successfully complete the project. Building Information Modeling software can be a powerful new method for facility managers to improve the efficiency of a building and more accurately manage operations over the life of a building (Brinda & Prasanna, 2014).

Usage of BIM technology among a building's lifecycle and information handover between lifecycle phases can benefit in terms of efficiency and effectiveness. This research focuses especially of the implementation and usage of BIM for the facility management of a building.

## **1.2.Problem Statement and Research Questions**

Recently, the demand for BIM is rising as global organisations and policymakers take the initiative to support BIM in the development of the building life cycle (Aziz et al., 2016). The existing BIM practice in FM scope, stakeholders are not completely enforcing BIM in the FM industry and most functions are conducted manually in current FM operations that adopted BIM, even facility managers recognizing that introducing BIM during organizational construction will reduce the probability of errors and improve performance (Becerik-Gerber et.al, 2014). Therefore the research questions are formed in order to achieve those barriers and reach to a point that is building lifecycle is enhanced with current technologies. Research questions are as follows;

How can BIM improve the efficiency on information and knowledge handover from construction phase to the operations phase of a complex project?

What are the objectives to overcome success barriers for BIM implementation into the building lifecycle of a complex project and how can we achieve those objectives?

What should be the effective approach to implement BIM for facility management in a large scale project?

### **1.3.Aims and Objectives of the Research**

The purpose of this research is mainly to investigate the development of BIM model for the efficient information delivery from building construction to operations, together with exploration of the possible areas that BIM can help in facility management to enhance conventional processes of operations and maintenance.

This thesis also analyses the adoption and execution of BIM in complex construction projects with a case study of Istanbul Airport. The purpose of the research is to develop the understanding of the benefits of BIM in such a large scale construction project in terms of both construction to operations handover and airport operations management. This thesis provides a conceptual guideline for implementation of BIM in the project lifecycle.

This thesis also aims to describe the improvement of delivery, implementation and execution of BIM in the Istanbul Airport.

The research will also outline the view on BIM within the complex construction, identify the advantages that improve the quality, duration, cost, manufacturing, planning and controlling with the help of BIM implementation.

Objectives of this thesis are as listed;

- To develop an understanding of advantages of BIM usage for facility management
- To provide a guidance of BIM implementation into the building lifecycle effectively and efficiently
- To examine the benefits of enabling BIM during the construction phase of a complex project for the information handover from construction to operation phases

### **1.4. Research Methodology**

First, a systematic literature review was undertaken in order to attain the aims listed in the previous section. In the literature review, related articles, journals, thesis, books and online documents were deeply examined to explain the concept of BIM and it's

implementation processes to the building lifecycle especially to facility management phase together with its benefits and barriers. In order to create a strong ground for the answers of the research questions and accomplishing the objectives of the thesis, a case study was done about the execution, implementation and delivery stages of a complex construction project, including the BIM based facility management activities and its potential benefits. Details of the research methodology will be discussed further.

### **1.5. Organization of the Thesis**

This section summarizes the content of this thesis by giving brief information on chapters.

In Chapter 1, introduction and background about the research are given. Purpose of the study and research objectives are explained briefly. Research methodology is briefly explained which is given in detail in the following chapters.

In Chapter 2, a review of the related literature about Building Information Modelling, background and brief definition of BIM are provided. Also development and implementation of BIM and details of building lifecycle are explained. Benefits and barriers of BIM implementation are also investigated in this chapter.

In Chapter 3, research methodology is discussed in detail, including research approach and data collection methods.

In Chapter 4, a case study will be determined in terms of all aspects from design to facility management stages.

In Chapter 5, results and findings of the study are given.

In Chapter 6, a brief conclusion about the thesis and review of the thesis objectives are given.

## **CHAPTER 2**

### **REVIEW OF BIM IMPLEMENTATION IN BUILDING LIFECYCLE**

In this chapter, the concept of BIM and its principles about implementation in the building lifecycle are explained in detail with the help of a wide-range literature review, in order to put a general understanding of BIM and its implementation process.

#### **2.1. Definition of BIM**

A widely accepted BIM definition is: "Building Information Modeling (BIM) is a digital depiction of the physical and functional aspects of a facility." A BIM is a mutual knowledge platform for information on a facility that forms a credible foundation for life-cycle decisions, described as occurring from earliest conception to destruction (U.S. National BIM Standard – NBIMS).

BIM includes various methodologies for an effective and efficient project lifecycle management, starting from the very beginning of a project to the facility management phases. One of them is reliable, standard marking or naming of records and data that allows to monitor and locate details over the life of the asset and guarantees that the same protocols are practiced by all those working on the project. An international standard regarding BIM use and implementation, ISO 19650 international Building Information Modelling standards which will be further detailed in the following topic, define a suitable procedure internationally for BIM use in projects. A BIM is basically a shared representation and spatial database that records any component's location and attributes.

A process for the sharing or disclosure of building details, including its construction, operation, performance and maintenance. This has historically involved the sharing, in paper or electronic format of drawings, schedules and manuals. The use of BIM will improve performance and minimize errors. Until construction goes on site, simulated structures are designed in three dimensions; the characteristics of all the components of the building can be found in the model; and design issues can be defined and settled instead of on site in the model, before the actual installations begin.

## **2.2. International Development of BIM**

BIM principles can be traced back to the early days of computing in the 1960s, and in the 1970s and 1980s, solid simulation systems started to appear. Many see the development of the ArchiCAD software program in Hungary in 1982 as the true origin of BIM, and the development of the Revit software program in 2000 saw a real change towards the effective implementation of BIM (Bergin, 2010).

Although the technology underpinning BIM has been around for over two decades, compared to industries such as manufacturing and engineering, BIM adoption and take-up in the construction industry has been relatively slow. Over the past five years, however, there has been a big change in momentum as technology and implementation challenges progress and the industry recognizes the tremendous benefits to be achieved by the use of this technology (RICS, 2013).

Industry Foundation Classes (IFCs) and aecXML (data structures for knowledge representation) built by buildingSMART are often associated with BIM. IFC is ISO-recognized and, since 2013, has become an official international standard, ISO 16739. (BuildingSmart International, 2013)

Construction Operations Building information exchange (COBie) is related to asset information delivery through BIM processes. COBie was designed by the United States Army Corps of Engineers' Bill East in 2007 and aims to gather and record equipment lists, inventory data sheets, warranties, spare parts lists, and preventive maintenance schedules. This expertise is used to help processes, repairs and asset management while a built asset is in use. (East, William, 2012) It was approved by the US-based National Institute of Building Sciences in December 2011 as part of its National Building Information Model (NBIMS-US) standard (ERDC, 2012). In September 2014, a code of practice regarding COBie was issued as a British Standard: BS 1192-4. The first two parts of ISO 19650 were released by ISO providing a structure for building information modeling based on process standards established in the United Kingdom. Further parts of the ISO 19650 series, with parts on asset management (Part 3) and security management (Part 5) published in 2020, form the basis of the UK BS and PAS 1192 specifications (Geospatial World, 2019). Part 4 which is about information exchange is still under development.

By mandating its use on their programs, building customers and government agencies are gradually becoming a driving force for the adoption of BIM, and technology and implementation problems continue to improve. (Smith, 2014).

Countries that later implemented BIM mandates, especially the United Kingdom, have developed mandates that specifically comply with the goal of reducing lifecycle costs; potential adopters are likely to do the same; and countries with current mandates are shifting their policies in this direction. (McGraw Hill Construction, 2014).

Together with those proposing a mandate, both countries mandating BIM want to make sure that their construction industries keep pace with emerging innovations and practices, believing them to be crucial to future success. In countries where BIM is not yet required for public buildings, there is a general risk of falling behind competing economies and a willingness to take advantage of business opportunities created by BIM in robust construction markets, whether in the country or abroad (McGraw Hill Construction, 2014). In Table 1, countries with national mandates are shown together with the BIM data requirements and prerequisites for projects in order to be included in the mandate.

**Table 1.** Countries with National Mandates (adapted from McGraw Hill Construction, 2014 )

Country	Name of Mandate	BIM Data Required	Building Sizes or Budgets Requiring BIM	Reasons for Establishing Policy
<b>Denmark:</b> Building & Property Agency under the Ministry of Climate, Energy and Building	Executive Order No. 118	Project lifecycle (architecture through O&M)	5M kroner and higher for national projects 20M kroner and higher for regional and municipal projects	Reduce building energy consumption Productivity improvement  Shorten the completion timeframe of programs  Improve teamwork and collaboration between team members
<b>Finland:</b> Senate Properties	Common BIM Requirement 2012	Project lifecycle (architecture through O&M)	All national public projects	Supporting the safe production and building lifecycle process Supporting the lifecycle planning and building process that complies with sustainable development Utilizing facilities management models

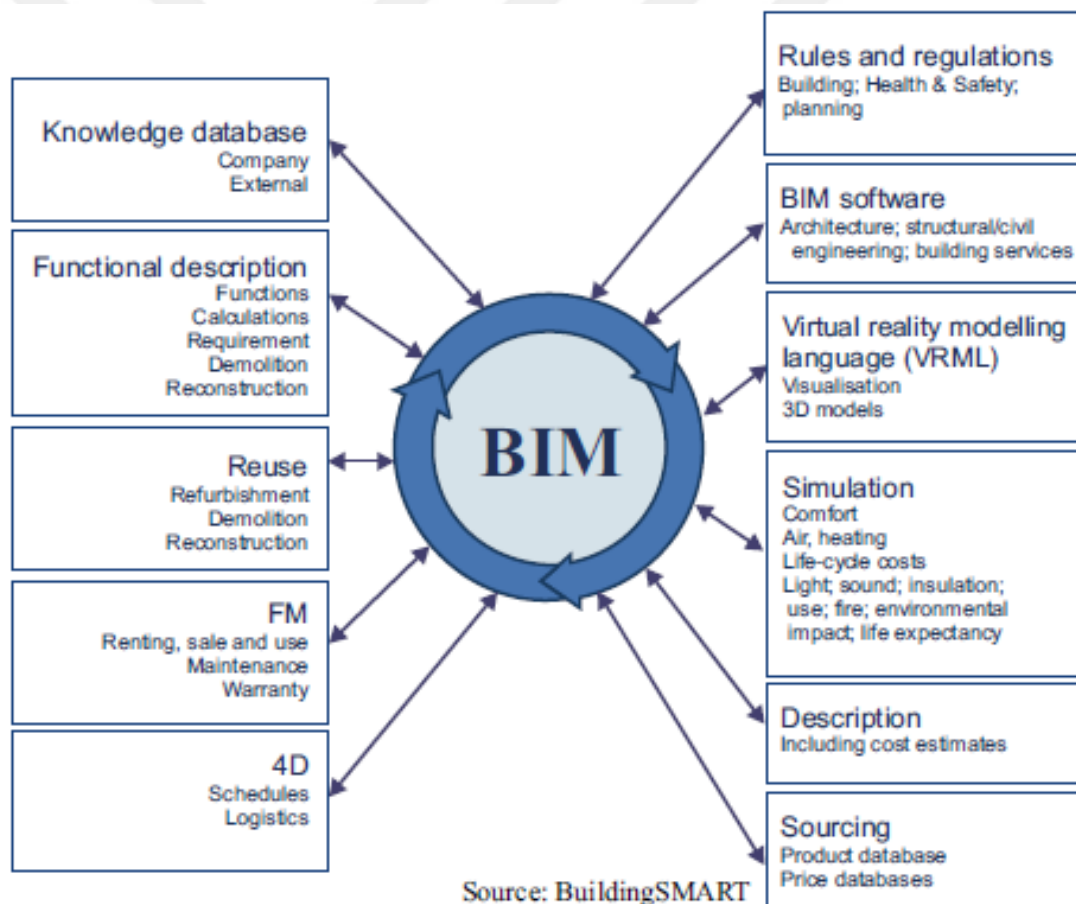
<b>Norway:</b> <b>Statsbygg</b>	Statsbygg BIM Manual 1.2.1	Architec- ture and handover data	All national public projects	Reduce errors and omissions Enhancing communications and collaboration Gain efficiencies Increase energy efficiency Use cutting edge research, technologies and processes to improve the built environment
<b>Singapore:</b> Building and Construction Authority**	BIM Road map and e- sub mission require- ments	Architec- ture and engineer- ing data	All new buildings over 20,000 sq.m.	Increase construction industry productivity by 20% to 30% over the next decade Achieve BIM use by 80% of Singapore's construction industry by 2015 Realize a highly qualified and technologically advanced construction industry led by advanced companies and backed by trained and professional employees in 2020
<b>South Korea:</b> Public Procurement Service (PPS)	BIM Guide Version 1.2	Architec- ture and property data	All public buildings costing over \$27.6M	Increase energy efficiency Reduce design errors Reduce construction costs Support efficient facility management
<b>United Kingdom:</b> The Cabinet Office of Government Construction Board	Govern- ment Construc- tion Strategy	Project lifecycle (architect- ure through O&M, defined in the U.K. As Level 2)	All national public projects	Reduce construction costs Reduce project delivery time Make UK's design and construction industry more Help UK meet carbon reduction targets for buildings

### 2.3. The Need for BIM

In the next few years, 95 per cent of building owners will implement BIM for new construction according to recent estimates,. There is a reason behind why building owners are pushing to implement BIM.

In addition to tracking the entire construction lifecycle, BIM-based systems will help to track any single component of construction processes and operations (LetsBuild, 2019).

During the planning, programming, design, and construction stages, the knowledge of a construction project gathered and generated by the project parties offers a tremendous resource of extremely useful information and data which may be used by facility owners and managers to increase the efficiency of operations during the building's lifecycle. The increasing use of BIM models for modeling, analysis, construction planning, 4D coordination, and manufacturing offers an incentive for the data in these models to be compiled and unified into an as-built model of facility record.



**Figure 2.** Fully Functional BIM (Source: BuildingSmart)

Instead of passing out printed documents and static records during the commissioning period, it is much more successful to integrate and create a live BIM model of the project.

The information in this model will facilitate the regular activities and planning needed in order to ensure that the facility continues to function successfully and at peak performance (Brinda & Prasanna, 2014). In Figure 2, a fully functional BIM aspects can be seen.

Indeed, it is smart for clients and new adopters to settle for a partial BIM. But each of the roles will carry and has much to learn from the common information pool. For any single feature, most BIM-based projects do not implement overall BIM yet, but choose the most suitable functions.

Autodesk's industrial viewpoint suggests that BIM technology enables AEC practitioners and facility managers to digitally "design, visualize, simulate and analyze key physical and functional" aspects of a building project prior to its physical completion. Engineers get a faster responses from Architects due to strong collaboration and other engineering fields, this improve design quality and good flow of work. Planners should, in their own words, pick the optimum sites for the project. Architects has the means to plan more precisely and fewer loss of time, less technical mistakes, which in turn lead to the expectations and vision of the owner of the facility. Contractors ensure that all problems relating to constructability are corrected and everything is down at the early stage of project implementation in order to prevent any costly design alteration costs. Building owners today and in the future have the potential to make full use of the building models. This acts as a simple instrument to direct the facility and its program of asset management. (Autodesk Inc. 2011)

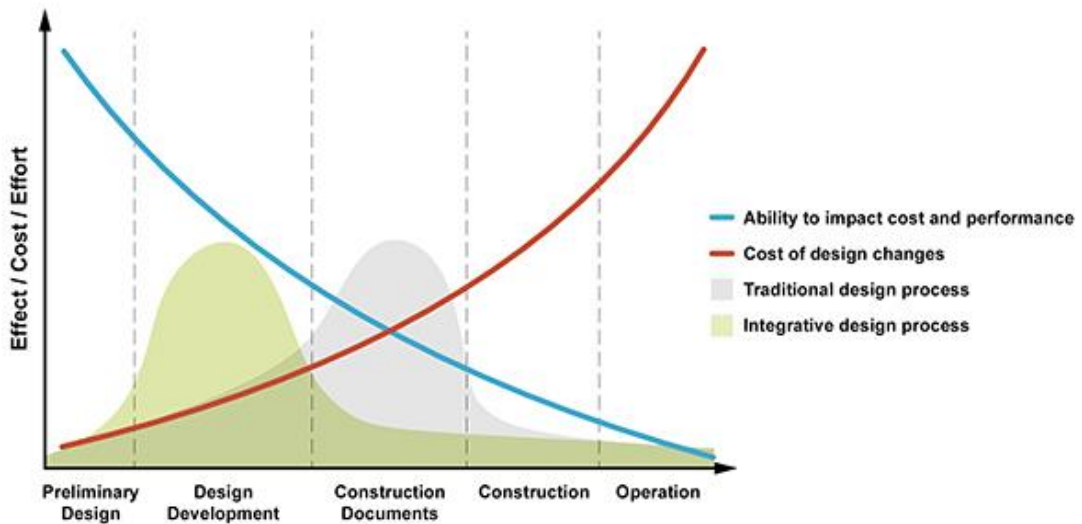
### **2.3.1. Benefits of BIM Implementation for Project Handover and FM**

BIM is internationally recognized as a project lifecycle management approach with many benefits. Successful implementation of BIM during the design and construction phases in a project is crucial for effective outcomes in facility management phase of a project. In Table 2, various benefits of BIM especially for design to operations handover process and facility management phase of a project.

**Table 2: Benefits of BIM Implementation for Project Handover and FM**

<b>Benefits of BIM for FM</b>	<b>Reference</b>
Automating the process of data transfer and update:	(Davtalaba and Delgadob, 2014)
Stronger role for FM	(SWG, n.d.)
Making sense of BIM data	(SWG, n.d.)
Improved Space Management	(Haines, 2016)
Facilitating Maintainability	(Davtalaba and Delgadob, 2014)
Set up Maintenance Activities Depend on Historical Trends	(SWG, n.d.)
Sustainability and Efficient use of Energy	(Haines, 2016)
Complete and accurate data that is linked directly to graphics	(McGraw Hill Construction, 2014)
BIM-FM software integration to eliminate double entry of information into their existing automated systems (the main purpose of the Construction-Operations Building Information Exchange [COBie] standard)	(McGraw Hill Construction, 2014)
Ability to capture real-time performance data in a “digital twin” of the physical facility	(McGraw Hill Construction, 2014)
Reliable as-built model that can be maintained in perpetuity	(McGraw Hill Construction, 2014)
Scheduled maintenance integrated into the model and work order systems	(McGraw Hill Construction, 2014)
Robust, iterative space management	(McGraw Hill Construction, 2014)
More accurate planning, scoping and budgeting for alterations	(McGraw Hill Construction, 2014)
Streamlined Maintenance	(Haines, 2016)
Economical Retrofits and Renovations	(Haines, 2016)
Enhanced Lifecycle Management	(Haines, 2016)
Effective operational cost	(Aziz et. al, 2016)
Shorter time for decision-making	(Aziz et. al, 2016)
Resource for decision-making	(Aziz et. al, 2016)
Better documentation system	(Aziz et. al, 2016)
Collaboration and work flexibility	(Aziz et. al, 2016)
Updated information and clash detection	(Aziz et. al, 2016)

Compared to conventional deployment and coordination approaches, the implementation of BIM ventures involves a radical change of work processes and habits (Carlsen, 2013).



**Figure 3.** MacLeamy Curve (Illustration by Daniel Overbey)

In Figure 3, The MacLeamy Curve reflects the idea that the higher the cost of design improvements, the more a project team is into the design process. For an integrative design method, it makes a good argument. BIM mechanisms pull project partners together faster than as in conventional methods, since before the model is assessed and quality assured, all preparations must be done. This has a beneficial result, a benefit, provided that the expense of improvements increases during the project process.

### **2.3.2. Barriers of BIM Implementation for Project Handover and FM**

There is a consensus on potential BIM applications and advantages in FM, demonstrated by the sponsorship of some groundbreaking FM organizations (Becerik-Gerber et al . 2012) and the vibrant efforts to address this field of research and development. At this point, the understanding of the challenges affecting BIM for FM applications is crucial.

The existing BIM practice in FM scope, stakeholders do not completely implement BIM in the FM industry and in existing FM operations that implemented BIM, most functions are still performed manually even though the facility manager knows that implementing BIM during operational construction will reduce the probability of errors and increase efficiency (Becerik-Gerber et. al, 2014).

Main barriers of BIM implementation is listed in Table 3 which are derived from a report by McGraw Hill Construction.

**Table 3.** BIM Implementation Barriers (adapted from McGraw Hill Construction, 2014)

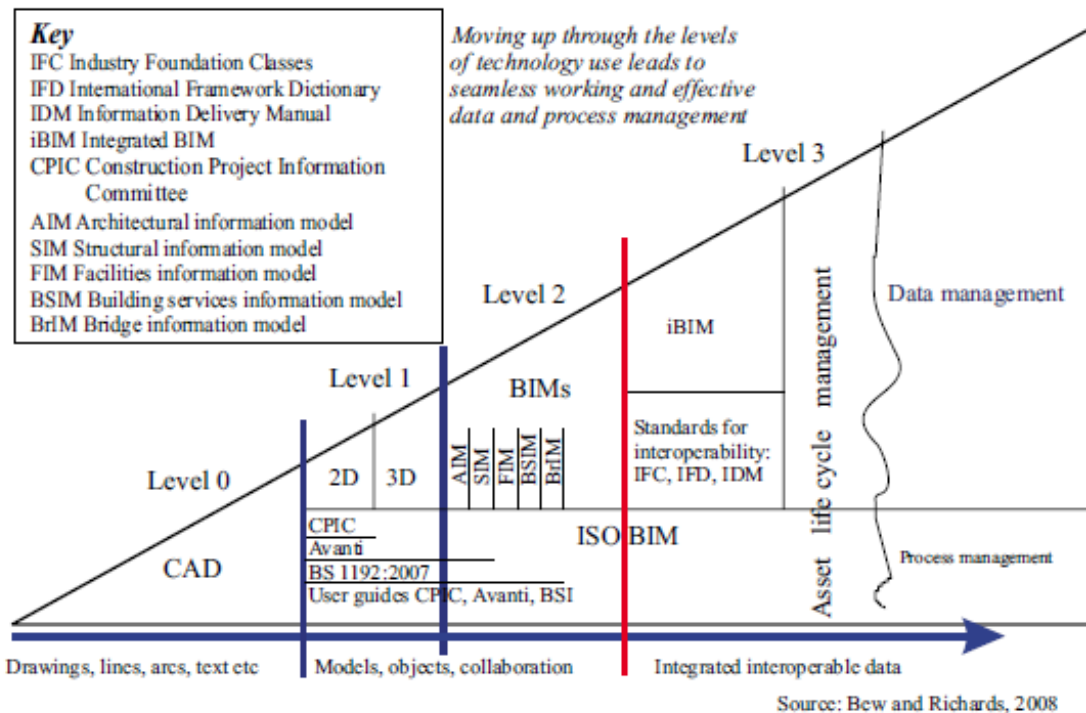
<b>Main Challenges</b>
Training Investment
Cost/Funding/ Initial Investment
Buy-In Among Industry/ Adoption on Wider Scale
Not as Adaptable for Small Jobs
Lack of Standards for BIM Across the Industry
Lack of Skilled Users

## **2.4. BIM Basics**

BIM is a development to guide the data developed during a project, from the initial stage of concept through planning, building, service and eventually demolition, to allow the best and most effective use of that data. In this section, technical principles of BIM will be explained.

### **2.4.1. BIM Maturity Levels**

The 'BIM wedge' was created in 2008 by Mervyn Richards, Head of IT at T5 at Heathrow airport, and Mark Bew, former head of the BIM Task Force. The 2008 Bew-Richards Wedge explains the evolution of the interactive and interoperable Building Information Paradigm from conventional CAD. Its aim was to illustrate BIM maturity, to give people a sense of their BIM maturity, and to provide a strategic roadmap for the growth of BIM implementation. The movement is referred to as 'BIM maturity' from one stage to another. The levels of BIM are explained accordingly in this topic and can be seen in Figure 4 (Barnes and Davies, 2014).



**Figure 4.** BIM Maturity Levels (Source: bsi, PAS 1192-2:2013)

Level 0 It sure isn't BIM at all. This applies to the use of 2D CAD files for details on design and development.

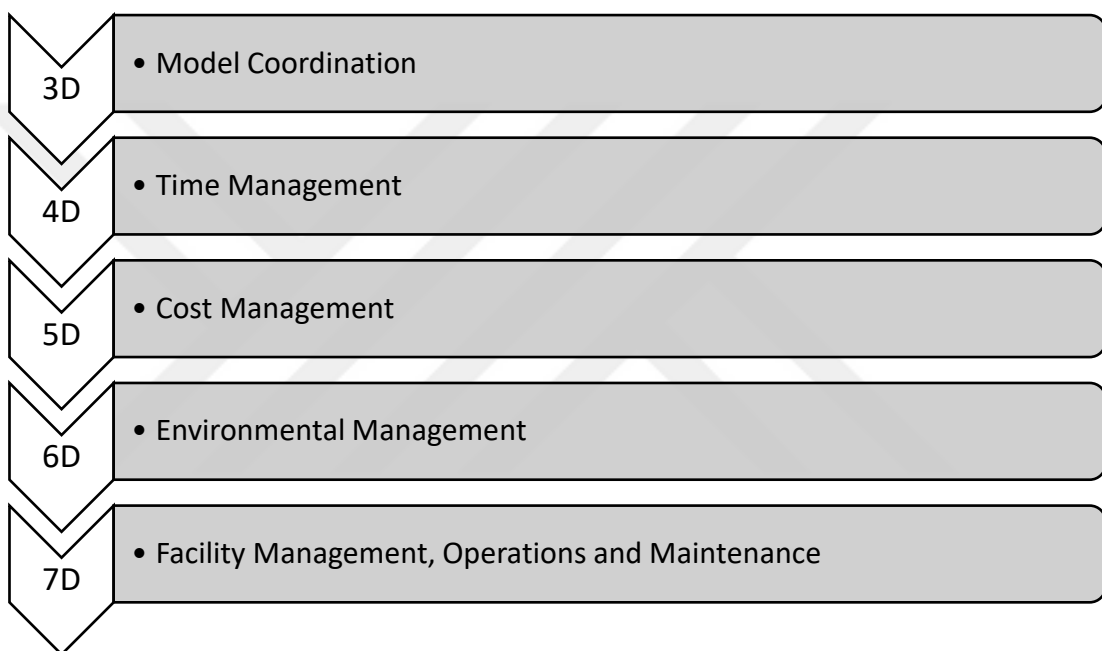
Level 1 is the first step towards true BIM and the use of 3D data to present concept is the first step. At this stage, designers generally use managed CAD in 2D or 3D format with shared resources to include a shared data environment where data structure and interface specifications are used.

Level 2 is an structured 3D format with data attached, held in different BIM discipline software resources. To correlate the work schedule, 4D BIM is used. Using costing systems that use model data, 5D or cost-driven engineering is carried out and is incorporated with BIM through proprietary interfaces.

Level 3 is the real-time project model would be completely incorporated and interactive, which is likely to be supported by online resources. 4D building sequencing, 5D cost information, 6D project life-cycle information and other dimension control information will be used in this BIM stage, and will be driven by the development of common object data libraries that will provide supplier information.

### 2.4.2. Dimensions of BIM

BIM processes can be conceptualized by adding dimensions upon the virtual models in 3D. Thus, The 3D model offers improved visualization, model operating, and identification of clashes. The 4D model offers the opportunity to schedule, plan, track and maintain a project. The 5D model allows for the calculation of quantity take-outs and real-time and life cycle costs. The 6D model includes the measurement and analysis of energy and discusses environmental distress. Facility operations, operation and maintenance, and life-cycle analysis are given by the 7D model. BIM Dimensions are listed in Figure 5 and detailed explanations are given in this section.



**Figure 5. BIM Dimensions**

BIM supports leaner building practices that can lead to higher prefabrication consumption ratios, decreased inventories of engineered-to-order parts, increased workflow stability, and improved coordination (Alarcón et al., 2013). Dimensions of BIM are explained in detail in the following paragraphs.

3D Model: BIM's ultimate aims are to maximize productivity in terms of time, costs, precision and thoroughness, to enhance coordination and to increase teamwork (Hardin, 2009). In intelligent Building Information Models, an exact representation of a completed project result may be visualized at an early level.

It is less difficult and more efficient to communicate design and engineering strategies between stakeholders in the project. Models and their interconnected details are always modified, and BIM makes changes and creation of real-time architecture. This usually strengthens collaboration and lets disciplines move towards a shared purpose together (Hattab and Hamzeh, 2013). Many potential contact errors are avoided by the model's interoperability and the digital exchange of information. Digital Information Requests (RFI) can be created by BIM, and in the model the installation of fabricated components is noticeable (Hardin, 2009). Owing to the fact that all specialization frameworks are merged under one core multidisciplinary model, rework and downtime on site is minimized. This allows project partners the opportunity to measure the effect of improvements more realistically and in real time on the final plan (Hattab and Hamzeh, 2013). When using BIM, client engagement and customer loyalty are improved. Involvement of the client in a BIM project would accurately translate the value proposition of the client (Hattab and Hamzeh, 2013). And by using 3D printers, the 3D model can be made into a physical manifestation in the future (Vandezande et al., 2011).

**4D Time:** The opportunity to plan structures, products and quantities by 4D visualisation opens up the inclusion of one dimension. Via this application, multiple sequencing and timing options may be checked and assessed for cost and/or viability (Harris and Alves, 2013). Using annotation on 4D BIM models will help to simplify possible construction issues, making decision-making supportive of the model. Trade planning includes collaborating and dealing with vendors and subcontractors, team managers, producers and suppliers, which, as the scale and scope of the project grows, becomes more demanding. One of the places where BIM really shines is trade coordination (Hardin, 2009). The constructability of the project is assured by analytical functionality such as collision control. Any time collisions are detected, monitored, and resolved before a project enters the construction process, the importance of BIM as a multiple trade coordination tool increases. The resolution and monitoring of collision detection helps construction site management to use BIM as an organic way to find problems with models produced by engineers and subcontractors (Hardin, 2009).

**5D Cost:** The Stanford University Center for Advanced Facility Engineering revealed that the use of BIM provides various advantages, including up to 40 percent removal

of unbudgeted improvements, 3 percent accuracy in cost calculation, up to 80 percent reduction in cost estimate generation time, saving up to 10 percent of the contract value by conflict detection, and up to 7 percent reduction in cost estimate generation time. (Chien et al., 2014). With BIM, budget preparation and accumulated tracking expenses can be carried out more effectively.

**6D Environmental Management:** Different building efficiency studies that can be performed on BIM models include power, lighting, solar effect, photovoltaic capacity, rainwater reclamation, computational fluid dynamics simulations, and LEED documentation (Vandezande et al., 2011). Such analyses are made possible by the interoperability of the model's geometry and metadata between applications.

**7D Facility Management:** Prior to the delivery of the finished project output to the owner, a final project review is carried out. (Hardin, 2009). For such jobs, BIM models may be used as punch lists. A BIM model is a facilities resource with warranty, specification and maintenance plan information that will ease the closure of the project and make it a quicker operation (Bryde et al., 2013).

It should be recalled that BIM really works in the field of construction if it is fully implemented. There is plenty of room for improvement and smoother interoperability between field systems and tools, but contractors who choose not to use this technology and leverage it to any or its fullest extent on the construction ground are losing a great opportunity (Hardin, 2009).

### **2.4.3. Information and Model Development**

BIM Models are produced in a developing concept beginning from less detailed to more detailed. It is not always required for a BIM model to be in full detail, the requirement of detail level can be defined in the beginning of a project. Level of Development concept and general requirements for model elements are explained in this section.

#### **2.4.3.1. Level of Development (LOD) Concept**

Level of Development (LOD) specifies what the model can be used for, and the degree of precision that can be expected from the programs of analysis. In any step of the project, the various stages reflect the planned use of the model. Below are the meanings of the five levels (Kensek, 2014):

LOD 100: Symbols or other common definitions may describe components. Because of the type of results, only logical analyses can be performed.

LOD 200: The model involves elements of the model, generalized structures, and assemblies in numbers, scale, form, and position that are estimated. It is possible to build simpler forecasts and schedules showing the phasing of major components.

LOD 300: The level of production of the model is equivalent to that of LOD 200, but the focus is on improved precision. At this point, the model can be used to create building papers, shop drawings, more comprehensive cost forecasts, scheduling, and performance-based analyses.

LOD350: The required coordination parts for the element are also presented in addition to LOD300. Support and connections are provided in these parts.

LOD 400: With the purpose of ordering, assembling, mounting, and specifying, the model has a much greater level of complexity. Virtual elements are very detailed and adequate to reflect, forecast and planning costs based on the committed sales costs and construction methods. LOD 400 shall be used during construction by general contractors and subcontractors.

LOD 500: In terms of their geometries, components have been field-verified, and reports of accumulated costs are available. Components can also contain design characteristics and component details, which are useful for facility operation and maintenance.

#### **2.4.3.2. Model Element General Requirements**

In a BIM Model, there are various elements that build the whole model including systems and disciplines such as architectural, structural, mechanical and electrical. In the following topics main disciplines of model elements and general requirements are explained.

##### **2.4.3.2.1. Architecture and Interior Design**

Architectural BIMs may provide details on both the structural composition of the building and the interior finishes and configurations of the space. As a general rule, two different BIMs should be modelled on these two types of knowledge. The BIM should be related to the overall architectural BIM, providing details about interior finishes and spatial configurations. Physical products and design, such as walls, floors,

and windows, may be architectural model components. Abstract artifacts such as rooms, spaces, and zones may, however, also be architectural model components. The model elements must, as far as possible, include all product information as properties of the model element for all architectural objects that represent tangible products and physical structure. The model components must have the functionality commonly seen in 2D schedules (GSA, 2016).

#### **2.4.3.2.2. Structural Engineering**

The structural model must describe the structure of the building and all its components correctly, including the elements, geometry, and materials. For each structural model feature, it must include the structure and material properties. For all materials in the BIM, as appropriate, hazardous material content is expected to be included as a property. Based on the material used for that element, the appropriate model element properties for each structural function can differ. The structural model shall include beam, column, and base components clearly labeled and completely dimensioned. In addition to relation information, material properties, cross-section properties, allocated structural analysis models, load cases including snow, wind, thermal expansion, seismic, etc.) load combinations, and load outcomes for the appropriate combinations, the structural elements of a building must specifically capture reinforcements and connections. Because of the complexities of the several different types of structural load situations, it is important to accurately model the structural system so that the linear and nonlinear analyses typically conducted on building systems to determine seismic loads are accurate and precise. Structural models shall include the following elements.

Foundations where it is important to completely model all the components of the base, including but not limited to isolated pads, bearing and retaining footings, stem walls, structural slabs, and piles.

Horizontal elements where it is important to completely model all beams, joists, slabs, and precast slabs. Slab perimeters and structural edges must be demonstrated by the model; penetrations for shafts, gaps, or other discontinuities of the slab; and cantilevered sections.

Vertical elements where it is important to completely model all columns, walls, and cross bracing. To allow load consistency, all connections and start/end points of such elements must be modelled.

Inclined planes which any structural feature that is inclined, including, though not limited to, non-plumb walls, stairs, ramps, and roofs.

Structural abstract components, including but not limited to loads and distributions of loads. (GSA, 2016).

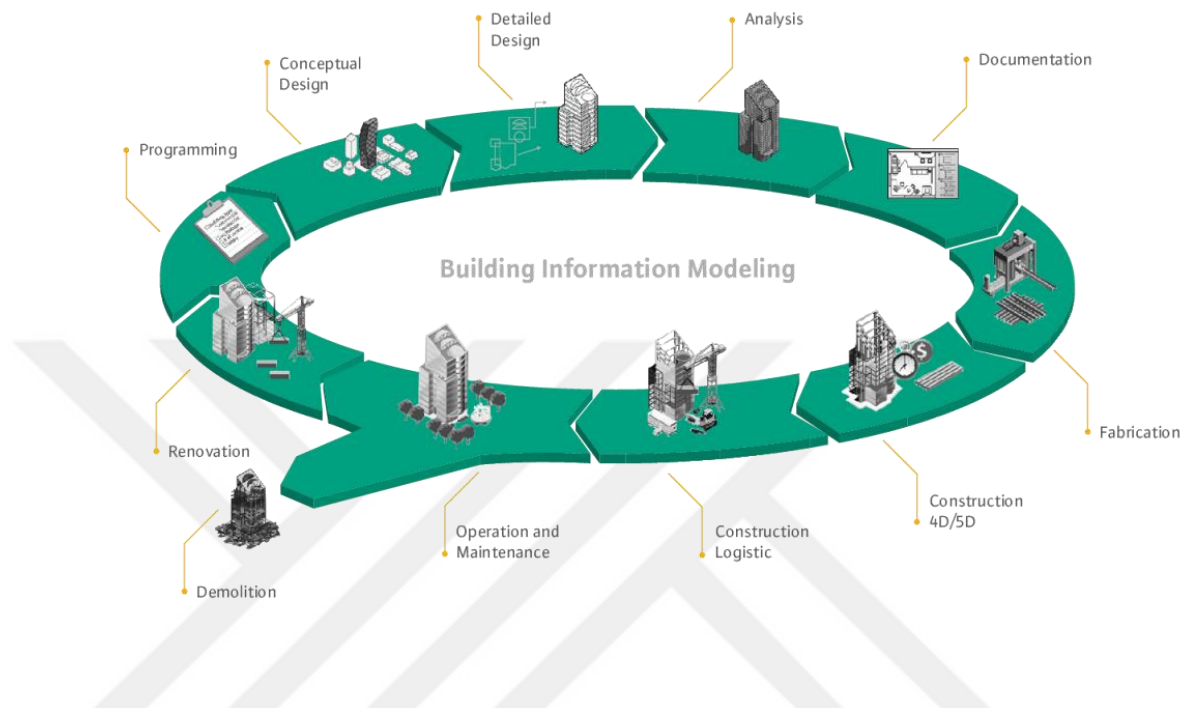
#### **2.4.3.2.3. Mechanical, Electrical, Plumbing (MEP) and Fire Protection (FP) Engineering**

The MEP and FP components shall correctly reflect the MEP systems of the building, including but not limited to boilers, chillers, pumps, water terminal units, fans, air handlers, air distribution and evacuation systems, air terminal units, VAV boxes, electrical feeding and distribution systems, transformers, electrical panels and switchboards. For all items in MEP models, all necessary details and properties must be included in the model elements to store schedule details. Hazardous substance content is necessary for all items in the BIM, as appropriate, to be included as a property MEP and FP objects may include additional energy properties such as insulation thickness. In order to demonstrate which equipment serves which spaces or floors, it is also important to verify that the MEP systems in the model are correctly separated. In the design of a building, various specialties are involved, and in the model the specialization knowledge must be registered (GSA, 2016)

### **2.5. Lifecycle of a Building**

According to NBIMS (2015), The BIM is a visual representation of the architectural and functional aspects of a facility. Planners, designers, architects, owners, and maintainers should share it to provide accurate decision making knowledge during the life cycle of the facility. In order to reduce the overall expense of owning and running a facility, BIM provides resources that allow decision-makers to consider all components of a facility, their location, and their characteristics, both graphically and systematically. BIM mainly facilitates knowledge capture, collaboration and teamwork during design and construction. BIM facilitates the performance management of a facility and the assets during the operations process. Full life-cycle BIM usage involves an enterprise BIM strategy for an owner, which entails

deployment at the level of the company. Enterprise BIM also promotes asset management (Shoolestani et al. 2015). In Figure 6 a typical building lifecycle can be seen where BIM is the main driver for all of the phases.



**Figure 6.** BIM Centered Building Lifecycle

Life-cycle management of the facility uses an organisational infrastructure of people, processes and technology (Motawa and Almarshad 2013). In facilities management (FM), BIM is used to improve operating effectiveness, save resources over the life of the facility and likely prolong the usable life of the facility (Smith and Tardif 2009). FM functions use a broad variety of data generated by an entity and its services (Patacas et al. 2015). With detailed knowledge about equipment warranties, routine repairs, and expected useful life of major building components, a facilities management model could substantially streamline the FM operation. In addition, the controls for building systems could be combined with the BIM to track the efficiency of the organisation. The FM BIM deliverable may be a concept model with design purpose details and as-built conditions, depending on the specifications of the owner, or it may also be the as-built model with full construction and fabrication information.

### **2.5.1. Handover of Information Between Project Phases**

All relevant information is integrated before construction work starts in order to build what is known as a digital twin of the construction. During the construction process, all stakeholders then have access to the twin and, subsequently, to the latest construction status and schedule. The digital twin becomes the property of the builder after the construction process, who can use the data to run the facility management cost-effectively. The information given by the digital twin can be used in the disposal and recycling of raw materials, including in the case of a building being demolished. BIM eventually rewards all stakeholders for this cause. (Wilo, n.d.)

Three main advantages of knowledge processing are at the core of BIM;

- Knowledge can be reused and repurposed once it is captured.
- It is possible to revisit and revise, correct and monitor details,
- Data can be checked and confirmed

Information and data gathering during a construction project, starting from its programming and conceptual design phases is crucial for the later phases of the project in terms of data development, documentation and ability to achieve historical data interactions. Hence, handing over the gathered information and data to the next phase carefully and successfully plays even more crucial role for a successful building lifecycle management, especially in the facility management phases.

Construction Operations Building Information (COBie) is a non-proprietary data format focused on providing asset data as distinct from geometric details linked with BIM models. Drawings, quantity bills and specifications provide details regarding the building in a typical construction project. A number of construction workers typically work to get this paperwork together. The paperwork could then be updated in the building process and handed to the customer. In fact, this does not always occur, or where it does, the data is presented in a format such as .pdf or paper, which makes it very difficult for the client to use (Hamil, 2018).

COBie is a performance-based standard for the distribution of data on facility properties. COBie requires two categories of assets: equipment and spaces. Although vendor data can one day be specifically accessible for installed products and equipment, COBie helps the project team coordinate electronic submissions accepted

during design and construction and produce a consolidated electronic O&M manual with little to no extra effort. COBie data will then be imported, again at no expense, directly into CMMS and asset management applications. The PDF, drawing, and BIM model files that accompany COBie are arranged so that they can be quickly accessed at the facilities management office using the protected server folders already in place (East, 2016). The theory behind COBie is that the key knowledge is all drawn into one format and shared among the construction team at designated stages of a project (Hamil, 2018).

FIATECH studies report that conventional handover execution by an Engineering, Procurement and Construction (EPC) is usually quantified as less than 0.3 percent of the project, but that the Owner/Operator (O/O) needs another 2-4 percent of the project cost to manually correct and key the necessary Operations and Maintenance (O&M) information into O&M systems. This implies that the handover usually only amounts to \$1 million for the EPC on a \$400 million project, but the O / O then needs to spend an estimated \$8-16 million on "hidden" data entry and validation costs. Studies by Fiatech have shown that frequent, standardized, non-proprietary, automated exchanges of information from EPC systems to O&M systems are projected to save 60% of this secret O / O expense, resulting in savings of between \$5-10 million on a project of \$400 million. There are four big concerns that must be tackled to optimize these savings (Bever, 2011).

### **2.5.2. Challenges in Construction to Operations Handover**

Owner-operators fail to collect operations and maintenance data on various properties in a functional manner when various departments are involved in a project, leading to costly project delays, fines, and industrial accidents. (Accruent, 2018).

Current facility handover information requirements enable contractors to create and supply a series of documents that provide the facility manager with little practical value. By re-keying the details contained in these handover records, facility managers begin their duties. The specification of the underlying industry foundation class (IFC) model with required business rules for use in the United States is COBie format. (East et. al., 2013) which is mentioned previously.

Bever, in an internet article of his, defines the information handover challenges under 4 main reasons as follows;

The first issue to be solved is the the big bang approach to information handover from the EPC to O&M staff. If data is not regularly assembled, distributed, and inspected during the project, O / Os frequently experience unforeseen start-up delays.

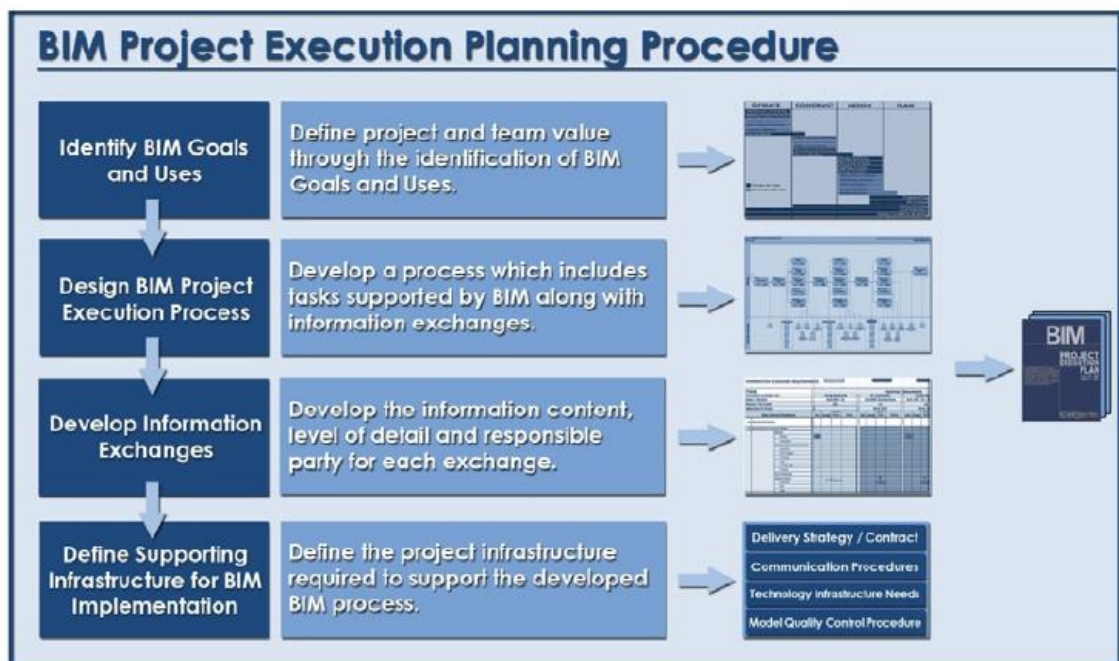
The second issue is the use of unstructured formats of data exchange for the transfer of knowledge from engineering to O&M employees.

The third issue is the proprietary handover information format for data exchange.

The final issue is the manual data exchange methods from Engineering and Building Systems to O&M systems to solve.

## 2.6. BIM Enabled Construction Management

BIM is a more effective way of managing information linked to the Project when compared to traditional 2D CAD systems.



**Figure 7.** BIM Project Execution Planning Procedure (Messner et al. 2011)

Adoption of BIM allows changes in work processes which can consolidate the performance in all construction projects. In Figure 7, there is a sample BIM project execution planning procedure is given.

Adoption of BIM is not only a change in technology; but also makes improvements to productivity. BIM is a mechanism in order to improve progresses to reach certain goals.

In order to achieve successful BIM implementation during the construction phase of a project, a structured approach should be taken for execution planning.

Ideally, a BIM model may offer detailed building information in an accurate 3D model that offers graphic views of the elements of a building and the ability to extract information on the quantity and product property to construction site supervisors and engineers (Eastman et al., 2011).

As a result of improved quality designs and less defects and allowing higher rate of prefabrication, building costs and schedules were reduced. A beneficial consequence of the opportunity to create design details reasonably early in the project is that it often prevents rework, which typically stems from unfinished details and incomplete paperwork. It is possible to model temporary parts, such as equipment and formwork. Both are essential to a project's sequencing and preparation.

Preparation of plans and estimates, supervision and management of improvements to work and shop drawings, and management of site logistics and temporary facilities and utilities, with specific regard to site safety, are the roles for which BIM can be most helpful to contractors (Aslani et al., 2009). During the design process, Aslani et al. sought to define the specifications of contractors for the preparation of BIM models so as to resolve the needs of designers, contractors and owners more effectively. A computational framework was developed by Wang et al. to investigate how BIM can be applied to the site using Augmented Reality (AR) (Wang et al., 2012). AR is a direct or indirect live view of an actual, real-world environment whose components are supplemented by sensory feedback provided by computers. Their research focused on the scientific and functional reasons for expanding BIM to building sites for regular comprehensive operation work, and how AR could play a critical role in promoting the quality of access to BIM knowledge. The researchers recommended a BIM + AR-based work pattern and concluded that the overall issues of site work were more prominent for both parties involved, making it easier to find and explore alternative solutions.

A important feature of BIM is the potential during the project to make knowledge accessible faster. The most valuable indicator of the importance of BIM is undoubtedly the number of requests for information (RFIs). The number of RFIs can be predicted to decrease dramatically with high-quality collaborative BIM. Since more RFI needs

work to be overcome, less RFIs equal more efficient time available for work and improved planning, development and service. However, some industry analysts have learned that RFIs are pushed to the front end of a project and do not diminish as much as they had anticipated.

## **2.7. BIM Enabled Facility Management**

BIM integrated facility management with a variety of space, asset and maintenance management features, incorporates the features of CAFM (computer-aided facility management) and CMMS (Computerized maintenance management system). And adds the benefit of having all project data integrated in various software platforms and cloud environment with spatial links to the multi dimensional digital twin model of the assets.

The ultimate goal of a BIM model is to use it in FM, regardless of whether the building is new or an existing one, which has the ability to dramatically decrease life cycle costs (Edirisinghe et. al., 2017). BIM has the option of providing a knowledge management system with traceability. It is possible to classify both specific quantities and positions of various items while the databases are related to the model. This helps personal maintenance to know the exact location of malfunctioning facilities and link it to the product details contained in the model-related databases. There are also opportunities inside the buildings to provide programs related to particular events. In a hospital setting, for example, there is a need to be able to track where such facilities have been, such as beds, washing appliances, and so on, to trace the spread of contamination.

With increased pressure on building owners and operators to minimize energy use and environmental effects, BIM allows for simulated pre-construction testing and review of building systems to ensure that sufficient steps have been taken to ensure expected efficiency and to modify underperforming systems before they are built.

Energy conservation and building performance are one area of significant concern for GSA and the building industry in new construction, major reconstruction and modernization, and building operations. In order to promote energy conservation, Table 4 indicates several ways to use BIM-based energy modeling during design.

**Table 4.** BIM-Based Energy Modeling Opportunities by Project Type (GSA, 2015)

Project Type	Project Challenge	Goal	Metrics for Success
New Construction and Major Renovation	Consistent and accurate analysis and prediction of building performance throughout the building lifecycle	Consistent and accurate energy predictions that result in energy efficient designs based on life-cycle costing	Life-cycle cost and estimated annual energy consumption that meets or exceeds project goals; accuracy and consistency in energy models
Renovation and Modernization	Consistent and accurate modeling of as-built conditions; calibration of energy models	Consistent and accurate energy predictions that result in the identification of the most cost effective energy efficient retrofits	Life-cycle cost and estimated annual energy consumption that meets or exceeds project goals; accuracy and consistency in energy models
Building Operations	Continuous commissioning using real-time energy modeling to evaluate actual and future building performance	Develop an energy modeling feed-back loop which evaluates building performance in realtime	Optimized energy performance, meeting or exceeding design intent; accuracy and consistency in energy models

Energy modeling is not a stand-alone technique; it is intended to facilitate integrated design - a process in which iteratively and in collaboration, various disciplines and design elements exist to enable synergies between different systems and components. Effective execution of this process involves teamwork and communication through the whole design process with the owner; developer; architect; mechanical, electrical, and structural engineers; landscape architect; and all other related design team members.

## **CHAPTER 3**

### **RESEARCH METHODOLOGY**

The topics for this section of the research include how this research was done. Details on the methodology of research including research approach, strategy and techniques of data collection are explained.

Prior to the case study, a wide range of resources were scanned and reviewed in terms of literature review including academical journals, articles, books, internet blog articles, whitepapers and case studies with the keywords especially including BIM and Facility Management. Prior to the literature review, research questions and objectives were defined in order to shape the structure of research and put an idea on the table. Research approach and strategy then defined to supply this research with robust information directly from the industry.

#### **3.1. Research Approach**

Two wide definitions have been used to outline various methods in order to clarify the essence of data collection and interpretation. There are quantitative approach and qualitative approach (Wilkinson, 2000).

##### **3.1.1. Qualitative Approach**

Surveys, tests, formal interviews, experimental studies and observation by non-participants are generally classified as ways of gathering quantitative data. One of the significant characteristics of quantitative research is that it is strongly organized and provides statistical analysis-enabled results. Structured questionnaires, for instance, typically require respondents to tick the required box to answer questions. Participants are usually not expected to say something about their own words. They actually have to agree with or disagree with comments made by the researcher. This technique makes it possible for the investigator to measure the data and determine how many entities have made a given claim.

The findings of quantitative studies, such as significance tests, correlation and regression analysis, are described in the form of descriptive or complex statistics. Quantitative analysis is concerned with expressing results in a numerical manner, as the name implies. (Wilkinson, 2000)

### **3.1.2. Quantitative Approach**

Observation of subjects, unstructured interviews or personal histories are typically perceived to be qualitative analysis approaches (Bryman 1988). The resulting data is provided in the form of quotes or explanations, although it is also possible to offer some simple statistics.

## **3.2. Research Strategy**

The five research approaches are survey study, ethnographic study, experimental study and case study, according to Fellows and Liu (2008). Since both case study and ethnographic study is considered to be used in this research, their definitions in detail are given in this topic.

A case study is an empirical approach that examines a current phenomenon in depth and within its real-world context, particularly where the differences between phenomenon and context may not be readily visible. In other words, since you wish to grasp a real-world situation and believe that such an interpretation is likely to involve significant contextual circumstances specific to your case, you would like to do a case study (e.g., Yin & Davis, 2007).

Ethnography research strategy is applicable to qualitative analysis, whereby the study needs to communicate with the respondent population for a given time to obtain the data needed. The ethnographic research methodology allows for the compilation of first-hand evidence from a specific research group or category (Murchinson, 2009).

In this research, both case study and ethnography methods are adopted as research strategy, since the researcher has directly been participated in Istanbul Airport project as Senior Engineer. Participating to many executive meetings and effectively taking roles in project delivery, BIM and facility management execution in the related project of case study make direct observation possible as the key aspect for the researcher.

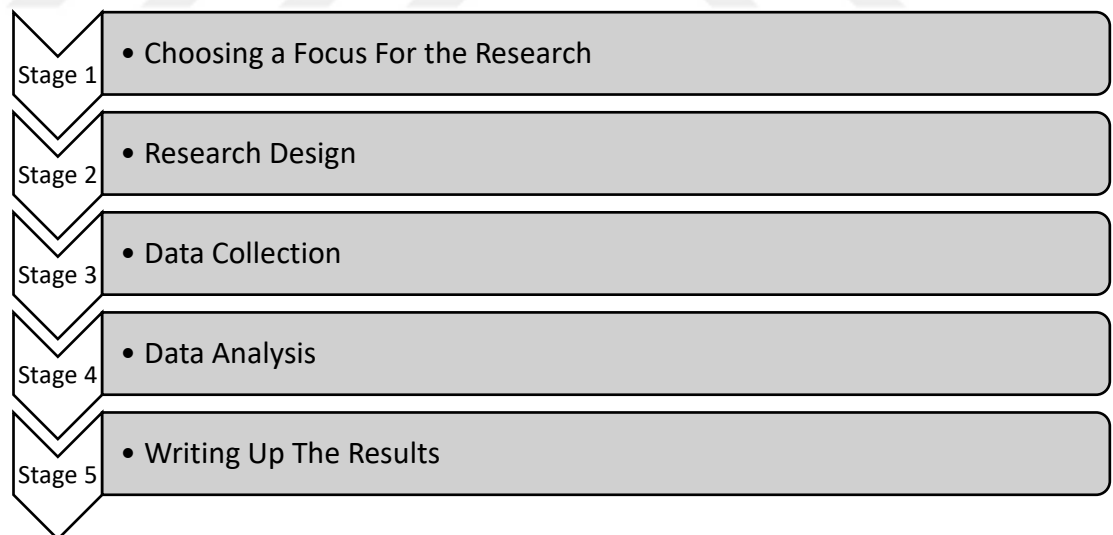
## **3.3. Data Collection & Data Analysis**

Data collection and interpretation are the most important elements of the research study. The data is regularly collected and the analysis of the collected data relates to

the research problem by clear method selection (Bryman and Bell, 2007). Data analysis is specifically responsible for the reliability and legitimacy of research (Wood & Ross, 2010). Therefore the two types of data collected for a detailed analysis are the primary data and secondary data for any study. In this analysis, primary data collection is adopted through direct observation of qualitative approach, while the researcher also worked as Senior BIM Engineer in the project and engaged in various executive processes during the project. Qualitative evidence is collected from direct experience, archive, one-to-one interviews and observation of processes.

### 3.4. Research Design

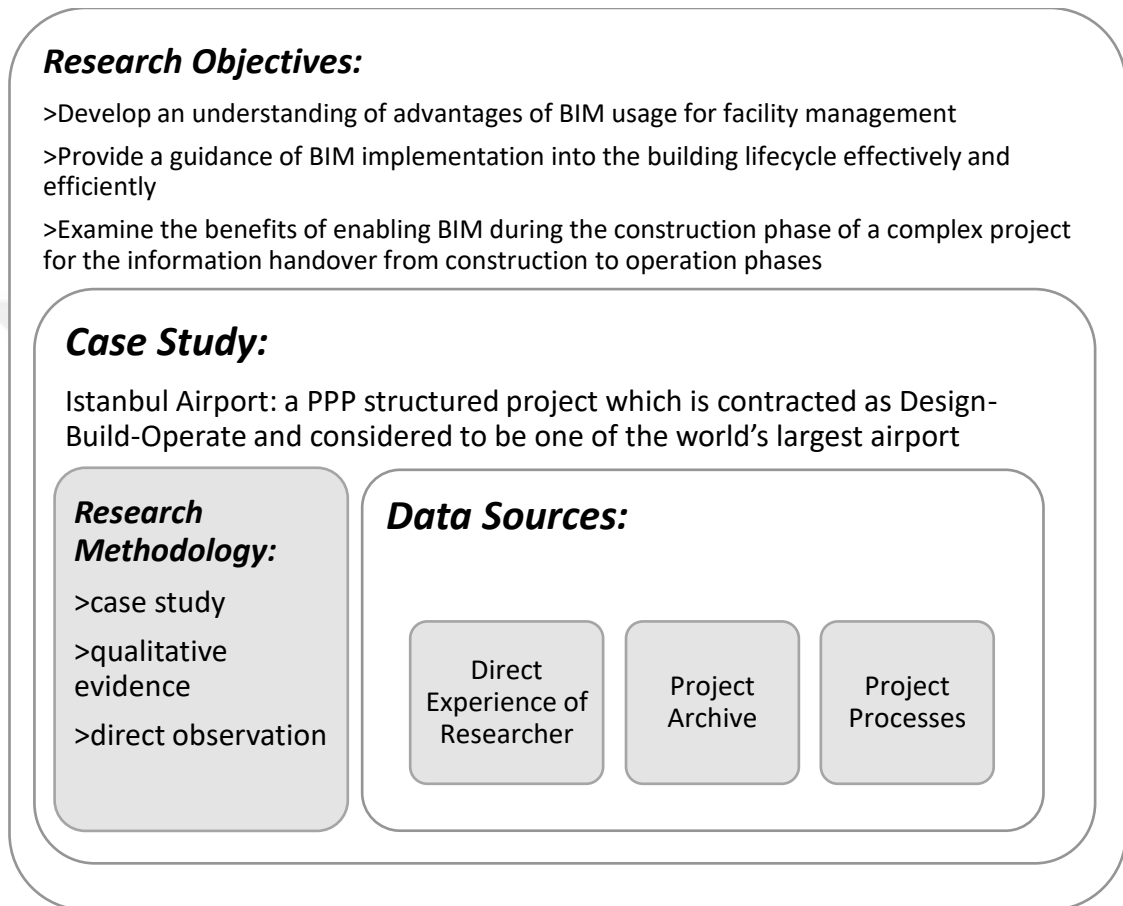
According to Wilkinson, a research design can be structured as five main steps as given in Figure 8, also adopted in this research. Although it can be used in any research, it is also subject to changes in the process of the research as nature and it not a strict roadmap. The research method, thus, is not a simple series of procedures following a straightforward pattern, but a messy relationship between the logical and empirical world, deduction and induction at the same time' (cit. in Bryman and Burgess 1994: 2).



**Figure 8.** Stages of Research (Derived from Wilkinson, 2000)

The best way to research what the researcher wants to know is to experience it for the researcher themselves, the context of the events being researched is important and a flexible approach to research is needed (Wilkinson & Birmingham, 2003).

In Figure 9, research objectives, case study, research methodology and data sources are summarized. Case study is the main source of information for the outcomes of this thesis. Together with the case study, a wide range review of literature is providing a strong infrastructure for the thesis objectives.



**Figure 9.** Summary of Research Design

## CHAPTER 4

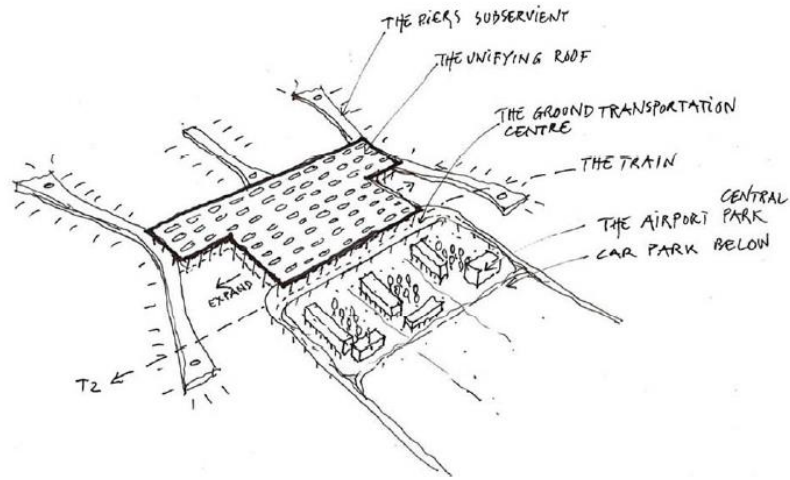
### A CASE STUDY OF ISTANBUL AIRPORT PROJECT – HOW DIGITAL AIRPORT BECOME A REALITY ?

#### 4.1. Project Information

Istanbul Airport (IGA) is an international airport under construction on the European side of Istanbul in the Arnavutköy area. The new airport is being built at the intersection of the Arnavutköy, Göktürk and Çatalca highways, north of the European side of Istanbul, between the Yeniköy and Akpınar regions of the Black Sea. Total construction area is nearly 76 square km. There are old open-pit coal mines in the field, which are to be filled with soil.

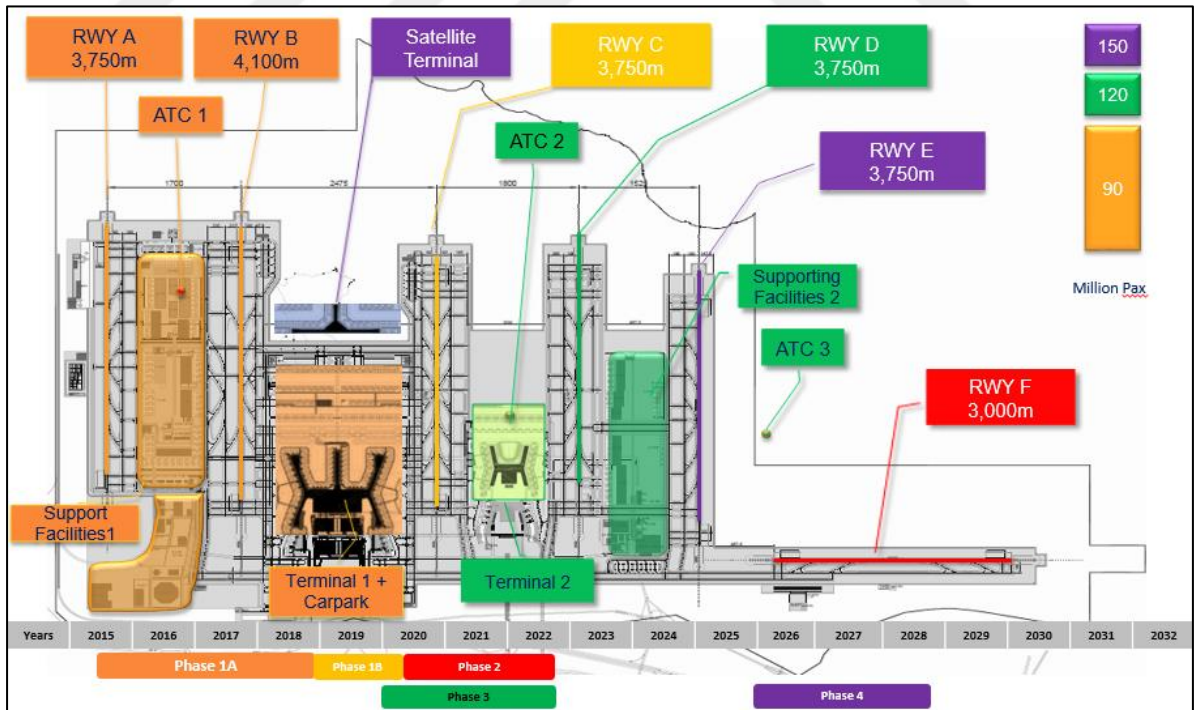
4 phases are defined by the project scope. The first phase entails the construction of three runways, a terminal containing five piers covering an area of nearly 1.5 million m<sup>2</sup>, a car park covering an area of nearly 700,000 m<sup>2</sup> and other supporting facilities. The critical assets of the main terminal structure, the runways and the associated emergency runway/taxiway system will be accomplished within the framework of the project. At the time of completion in 2018, with a gross floor area and the capacity to accommodate 90 million passengers a year, Istanbul Airport has the world's biggest terminal under one roof.

The architectural design of the terminal at Istanbul Airport is closely related to the character of the city and will serve as an excellent gateway to Istanbul and Turkey. An early design sketch of Istanbul Airport can be seen in Figure 10.



**Figure 10.** Early Design Brief of İstanbul Airport

The terminal building, considering its scale, is constructed as one that sits quietly, with a simple horizontal expression, in its background. Train, subway, bus, coach and parking are smoothly integrated between the terminal and the planned Airport City across a generous plaza and an accessible traffic forecourt on the landside.



**Figure 11.** Istanbul Airport Master Plan in Phases

A groundbreaking scheme will come to life at the completion of all stages, delivering 76 million square meters of airport field and 6 runways, accommodating 3,500 take-offs and landings per day, 200 million passengers a year and access to 350 destinations worldwide. IGA Master Planning phases can be seen in Figure 11.

The airport project includes runways, passenger terminals, Air Passenger Movement (APM) Station, cargo terminal, maintenance hangars, cargo apron, Air Traffic Control (ATC) Towers, ancillary buildings; general aviation buildings; VIP terminal, fuel farm, fuel delivery jetty, fire services, a metro link; airport service, hotels & offices, roads and airport connector roads.

TERMINAL BUILDING LEVEL DETAILS			PIERS LEVEL DETAILS		
LEVEL CODE	ELEVATION	LEVEL DESCRIPTION	LEVEL CODE	ELEVATION	LEVEL DESCRIPTION
L	+42.00	Roof Level	G	+22.00	Roof Level
K	+31.90	Office / Hotel Roof	F	+13.50	Arrival Level
J	+28.10	Office / Hotel Level 3	E	+ 6.50	Departure Level
H	+24.30	Office / Hotel Level 2	D	+ 0.00	Ramp Accm. & C Gates
G	+20.50	Retail Mezzanine / Office / Hotel	B	-12.00	APML
F	+15.00	Departure Level			
E	+ 8.00	Mezzanine Level	CARPARK LEVEL DETAILS		
Y	+ 3.50	BHS Mezzanine	LEVEL CODE	ELEVATION	LEVEL DESCRIPTION
D	+ 0.00	Arrivals Level	K301	+15.00	Level 3
C	- 7.00	Escape Corridors	K201	+10.00	Level 2
B	-12.00	Basement Level	K101	+ 5.00	Level 1
A	-20.00	Metro and Train Station	Z001	+ 0.00	Ground
			B101	- 4.20	Basement 1
			B201	- 8.40	Basement 2
			B301	-12.60	Basement 3

*Figure 12. Terminal, Piers and Carpark Levels*

Terminal Buildings consist of 3 zones which are also divided in architectural subzones separately to easy coordinate and understand the process in project easily.

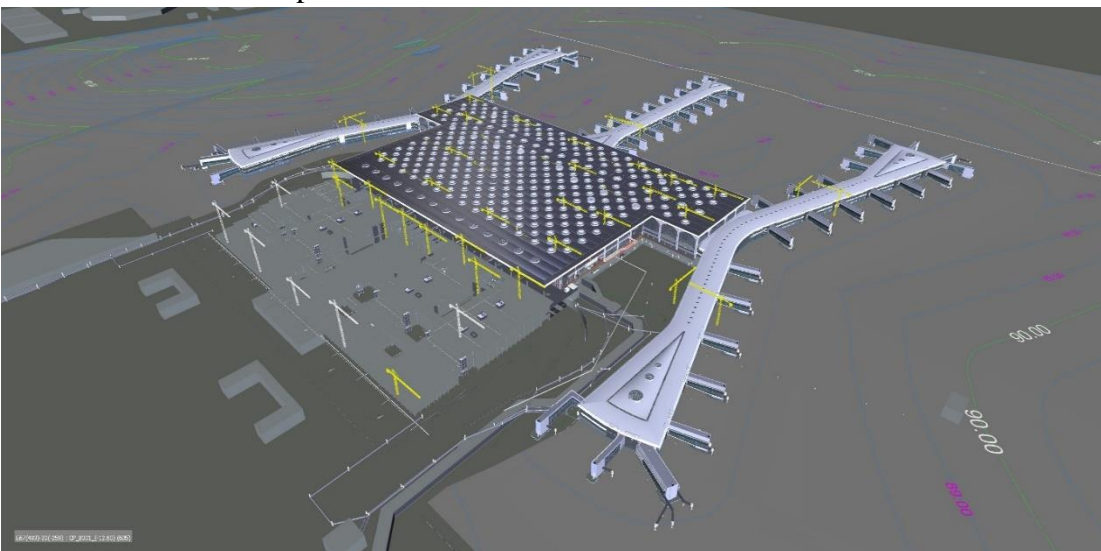
Terminal Building (TB)			Pier Building (PB)					Carpark (CP)				
TB-1	TB-2	TB-3	PB-1	PB-2	PB-3	PB-4	PB-5	CP-1	CP-2	CP-3	CP-4	CP-5
TB-1-1	TB-2-1	TB-3-1	PB-1-1	PB-2-1	PB-3-1	PB-4-1	PB-5-1	CP-1-1	CP-2-1	CP-3-1	CP-4-1	CP-5-1
TB-1-2	TB-2-2	TB-3-2	PB-1-2	PB-2-2	PB-3-2	PB-4-2	PB-5-2	CP-1-2	CP-2-2	CP-3-2	CP-4-2	CP-5-2
TB-1-3	TB-2-3	TB-3-3	PB-1-3	PB-2-3	PB-3-3	PB-4-3	PB-5-3	CP-1-3	CP-2-3	CP-3-3	CP-4-3	CP-5-3
TB-1-4	TB-2-4	TB-3-4	PB-1-4	PB-2-4	PB-3-4	PB-4-4	PB-5-4	CP-1-4	CP-2-4	CP-3-4	CP-4-4	CP-5-4
TB-1-5	TB-2-5	TB-3-5	PB-1-5	PB-2-5	PB-3-5	PB-4-5	PB-5-5					
TB-1-6	TB-2-6	TB-3-6					PB-5-6					
TB-1-7	TB-2-7	TB-3-7					PB-5-7					
TB-1-8												

*Figure 13. Architectural Subzones for Key Buildings*

Project levels are given in Figure 12 for Terminal, Piers and Carpark for use in accurate design processes. Similarly, Pier Buildings and Carpark Buildings have subzones that are listed in Figure 13.

#### **4.2.BIM Execution in Istanbul Airport**

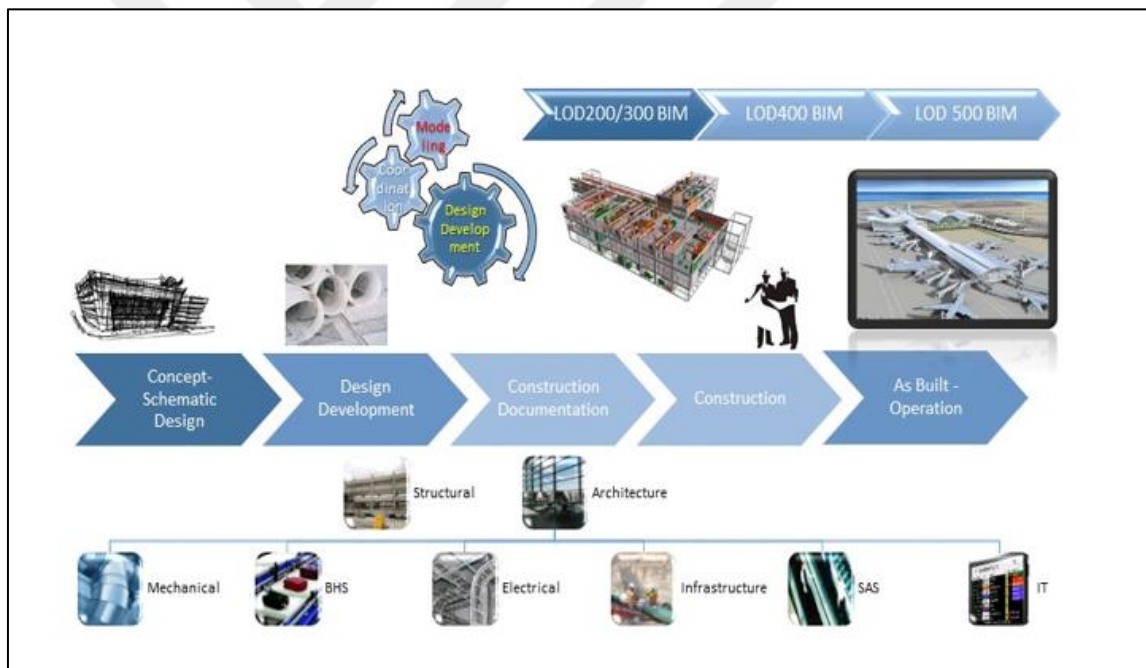
Brian Smith, Application Services Consultant for Invicara, a technology and innovation company explains that; “Airports are like self-contained miniature cities. They have their own police force, medical services, restaurants – and thousands of people moving through every day. This creates a lot of data – and airports need a way to stay on top of it. So, when something goes wrong, there’s a lot at stake. That’s why BIM is essential for airport management – a centralized location for all the information related to things like safety access, vendor leasing information, user manuals, asset location could mean the difference between a manageable issue and a catastrophic event. Any amount of downtime for an airport is astronomical.” Being one of the world’s largest airport, İstanbul Airport project is a huge challenge in both construction and operation phases. Istanbul Airport, also one of the finalists in the 2016 AEC Excellence Awards for Autodesk, brings the new technology and digital transformation to the airport's design and service. One of them is BIM, which facilitates construction processes such as architecture and engineering, project management, cost management, building management and asset management of facility operations. It is possible to construct a real digital mirror of the physical world for the first time. IGA has a BIM Workflow that consists of BIM Integration, BIM Production and BIM Management. A snapshot of Terminal Building representing the model in construction phase.



**Figure 14.** Construction Phase Terminal Model Snapshot

IGA BIM Department has collaborated with an outsourced company in order to execute and implement BIM processes and deliver BIM models.

There is an all-inclusive strategy for BIM execution which includes almost every discipline for seamless coordination between parties for overall project delivery and supply chain management. Considering the size and complexity of the project, using conventional methods for project delivery is unimaginable. In Figure 15, a generalized strategy flow for Istanbul Airport is illustrated. As seen in the figure, structural, architectural, mechanical, BHS (Baggage Handling System), electrical, infrastructural, SAS (Special Airport Systems) and ICT (Information and Communication Systems) disciplines are included in the BIM execution strategy. Since the ultimate aim to build a BIM model is using it in the operational phase, all systems related to operational phase are included in the BIM model.



**Figure 15. Istanbul Airport BIM Strategy**

Autodesk products are fully integrated. In terms of information management; Autodesk Vault and Autodesk Buzzsaw are being used. 3D/4D modelling and coordination environment is provided by Revit & Navisworks. All engineering and coordination end product is delivered to site as well as site supervision and all QA/QC processes of all disciplines done by mobile tablets using Autodesk BIM360 (Glue, Field, Layout) apps. Besides, Basecamp is used for communication with modelling team.

BIM Integration includes IGA officials and subcontractors from all design disciplines and QA/QC. The information and design deliverables (2D and/or 3D) from all disciplines will be submitted to Vault in 2-week intervals. Document submissions will be logged by Project Coordination Team and reported to BIM Management and submitting discipline officials after each submission.

BIM has an important role for strategic processes by upholding the integration of all related stakeholders and all relevant disciplines which are architecture, structure, MEP (Mechanical, Electrical and Plumbing), BHS (Baggage Handling System), IT etc. at such a major and complex infrastructure project. In Figure 16, LOD Matrix Index sample can be seen which shows a grouped list of objects in the BIM Execution Planning subject to LOD matrix data.

LOD MATRIX INDEX				
ARCHITECTURE	STRUCTURE	HVAC	PLUMBING & FIRE PROTECTION	ELECTRICAL
WALLS	CONCRETE COLUMN	AHU	NRV	CABLE TRAY
DOORS	STEEL COLUMN	ATTENUATOR	FLOAT VALVE	SMOKE DETECTOR
WINDOWS	CONCRETE WALL	CHILLED COIL	BALL VALVE	HORN WITH FLASHER
INTERIOR GLAZED PARTITIONS	RETAINING WALL	CHILLER	GATE VALVE	CO DETECTORS
INTERNAL SCREENS	CONCRETE BEAM	PUMP	FLOOR DRAIN	FIRE ALARM CONTROL PANEL
FLOORS	STEEL BEAM	VAV	SUMP PUMP	LIGHTING DIMMER SWITCH
CEILING	POST-TENSIONED BEAM	JET FAN	DOMESTIC WATER PIPING	RECESS LIGHT
ROOMS	STEEL LATERAL BRACING	EXHAUST FAN	SANITARY SEWERAGE PIPING	FLUORESCENT FIXTURE 1X28 W
LOUVERS	STEEL TRUSSES	LINEAR DIFFUSER	WATER BOOSTER PUMP	CAMERA
EXTERNAL FACADE	FOOTING & PILE CAPS	LOUVER DIFFUSER	EXPANSION TANK	RACK
SKYLIGHTS	STRUCTURAL COLUMN	DUCT	WATER FILTER	INTERCOM
ROOF	FOUNDATION SLAB / RAFT	HEAT EXCHANGER	PIPING ELBOW	EMERGENCY CALL POINT
	FLOOR SLAB	DUCT FITTING	PIPING TEE	MOTION SENSOR
	POST-TENSIONED SLAB	DAMPER	PIPING REDUCER	DISTRIBUTION BOARD
	STAIR	HEATING UNIT VENTILATOR	WATER HOSE HUB	TRANSFORMER
	RAMP	FCU	FLEXIBLE JOINT METAL	GENERATOR
	PARAPET / UPSTANDS	COOLING TOWER	FIRE PROTECTION PIPING	CIRCUIT BREAKER SWITCHBOARD
		BOILER	UPRIGHT SPRINKLERS	UPS
		CHILLED BEAM	FIRE EXTINGUISHERS	LV CAPACITOR BANK
		CASSETTE UNIT	FIRE HYDRANTS	MCC
		FLEX DUCT	WATER HEATER	CENTRAL BATTERY SYSTEM
		PLENUM BOX	SIDEWALL SPRINKLERS	JUNCTION BOX
			PENDENT SPRINKLERS	SINGLE SWITCH SOCKET
				COLUMN SPEAKER
				DISH ANTENNA
				WIRELESS ACCESS POINT
				CONTROL PANEL
				SMOKE DETECTOR WITH LED
				MOMENTARY SWITCH
				ONE GANG METAL CLAD SWITCH
				TWO GANG SWITCH
				LM-8 2X54 W
				LM-9 2X54 W
				LM11A-2X26W
				LM-12 2X18 W
				LM13A-2X26W
				LM-2 1X150W
				LM-27 4X14W
				LM-7 4x14 W
				LUM-2 COB LIGHT
				SINGLE UNSWITCH SOCKET
				COMBINED SOCKET METAL CLAD
				WATER PROOF SOCKET
				UPS SOCKET
				CEILING SPEAKER

**Figure 16. LOD Matrix Index**

BIM Production is where all design information (which includes but not limited to 2D layouts, sections, elevations, schedule, design specifications etc.) is incorporated into 3D BIM model. Vault submissions are synchronized to Buzzsaw continuously to ensure information on both environments is up-to-date. BIM Production Team works under administration of BIM Management Team and responsible for BIM modeling starting from LOD200 (PD2), LOD300 (IFC), LOD400 (Shop Drawing) to LOD500

(As-Built). BoQ extraction from BIM model, clash detection and reporting, 4D schedule simulation will be performed regularly.

Together with the LOD Matrix Index, all related systems and equipments are defined in detail. In Figure 17, details of a sample equipment in each development phase of the BIM model can be seen. This details include description of the model development details for every LOD level in the project.

INFORMATION CATEGORY	INFORMATION ITEM	LOD 200		LOD 300		LOD 400		LOD 500		
		YES/NO	DESCRIPTION/SNAP	YES/NO	DESCRIPTION/SNAP	YES/NO	DESCRIPTION/SNAP	YES/NO	DESCRIPTION/SNAP	
PHYSICAL PROPERTIES	Length	Y	Generic Element : schematic layout with approximate size/shape/location of equipment ; Design performance information ; Approximate access / code clearance requirements represented in the model	Y	Specific Element: modelled as designed specified size/ shape/ spacing/ location of equipment; approximate allowances for spacing and clearances required for all specified anchors, supports, vibration and seismic control that are utilized in the layout of equipment ; actual access/code clearance requirements represented in the model	Y	Detailed element: modelled as contractor submitted actual size/shape/spacing/ location/ connection of equipment's; actual size/shape/spacing/ clearances are required for all specified anchors, supports, vibration and seismic control that are utilized in the layout of equipment in line with manufacturer/contractor requirements and for fabrication and field installation	Y	Detailed as built condition/field changes: modelled to suit the co-ordination/field changes to use further for record model. Facility management and further use	
	Width	Y		Y		Y		Y		
	Height	Y		Y		Y		Y		Y
	Nominal Size	N		Y		Y		Y		Y
LOCATION PROPERTIES	Building ID	N	N	Y	Y	Y	Y	Y	Y	
	Building Name	N	Y	Y	Y	Y	Y	Y	Y	
	Floor ID	N	N	Y	Y	Y	Y	Y	Y	
	Floor Name	N	Y	Y	Y	Y	Y	Y	Y	
	Zone/Space Name	N	Y	Y	Y	Y	Y	Y	Y	
	Zone/Space ID	N	N	Y	Y	Y	Y	Y	Y	
	Elevation	Y	Y	Y	Y	Y	Y	Y	Y	
ANNOTATION PROPERTIES	System	Y	Y	Y	Y	Y	Y	Y	Y	
	Sub-System Abbreviation	N	Y	Y	Y	Y	Y	Y	Y	
	Mark	Y	Y	Y	Y	Y	Y	Y	Y	
QUANTIFICATION PROPERTIES	BOQ	Y	Y	Y	Y	Y	Y	Y	Y	
	WBS number	N	N	N	N	N	N	N	N	

**Figure 17. LoD Matrix for MEP/AHU(Air-Handling Unit)**

BIM Management gathers project information from all disciplines through Vault and Buzzsaw environments. BIM Management is responsible for BIM based project coordination, BIM model management and integration of design, schedule, quantity and as-built information. The coordination of the project is accomplished by weekly BIM coordination meetings and workshops where critical issues and other project problems are solved. Request for Information documents (RFIs) are an important part of every project. It is evident that any time there is some improvement in the plan, it is appropriate to lift any demand in terms of RFI project information requesting the required details. It is effectively an authorized electronic format to keep track of all changes and improvements and knowledge sharing. A basic procedure has been shown below to track and manage all the RFI's and a cumulative log is kept that will be revised weekly and mirrored in Buzzsaw as well.

The RFI format and response are described in Figure 18 for Terminal Building E level MEP discipline together with snapshots of both 2D drawing and 3D model of the subject area in the RFI. These snapshots are included in the relevant RFI in order for the recipients to clearly understand the issue.

iGA			
INA PROJECT			
REQUEST FOR INFORMATION (RFI)			
ORIGINATOR COMPANY :		RFI NO : INV-BIM-MEPF-TB-00274	Revision: A
Subject / RFI Topic :	MEPF Services clashes with Architecture wall as per IFC		
From:		TO :	
Date:	26.12.2016	CC:	
Response Required By:	28.12.2016		
Disciplines :	MEPF	Attachments:	3 Snap
Building Code :	TB	External References:	
Zone :	TB1/TB2 - 3,4,5		
Level:	E		
Grid:	As shown		
<b>QUESTION OR CONCERN</b>			
1. In Terminal Level-E we have many critical clashes with architecture wall where it is almost impossible to avoid the MEPF service clash. This are mostly in toilets, locker rooms, recessed wall area etc. The same have also been marked for easy reference.			
<b>ANSWER</b>			
All issues has been responded with Navisworks XML viewpoint comments during TB-E coordination. Please close the RFI.			
			

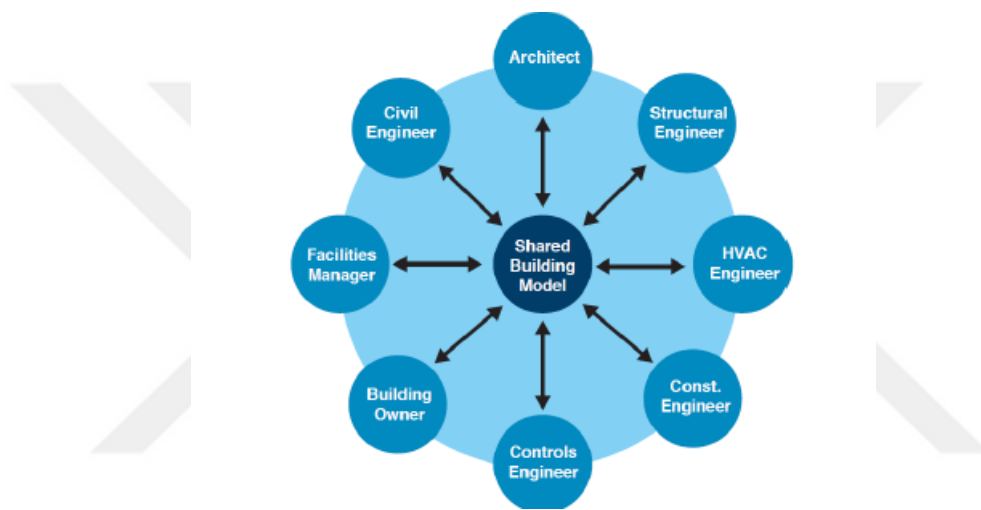
**Figure 18.** RFI example for MEP with answer and attachments

### 4.3. Construction Management with BIM

Implementation and execution of Building Information Modelling have numerous benefits for Istanbul Airport Project in terms of Quality Assurance and Quality Control (QA/QC), planning, Test and Commissioning (T&C), Energy Analysis & Solar Analysis & Sustainability and Operation and Maintenance (O&M) aspects.

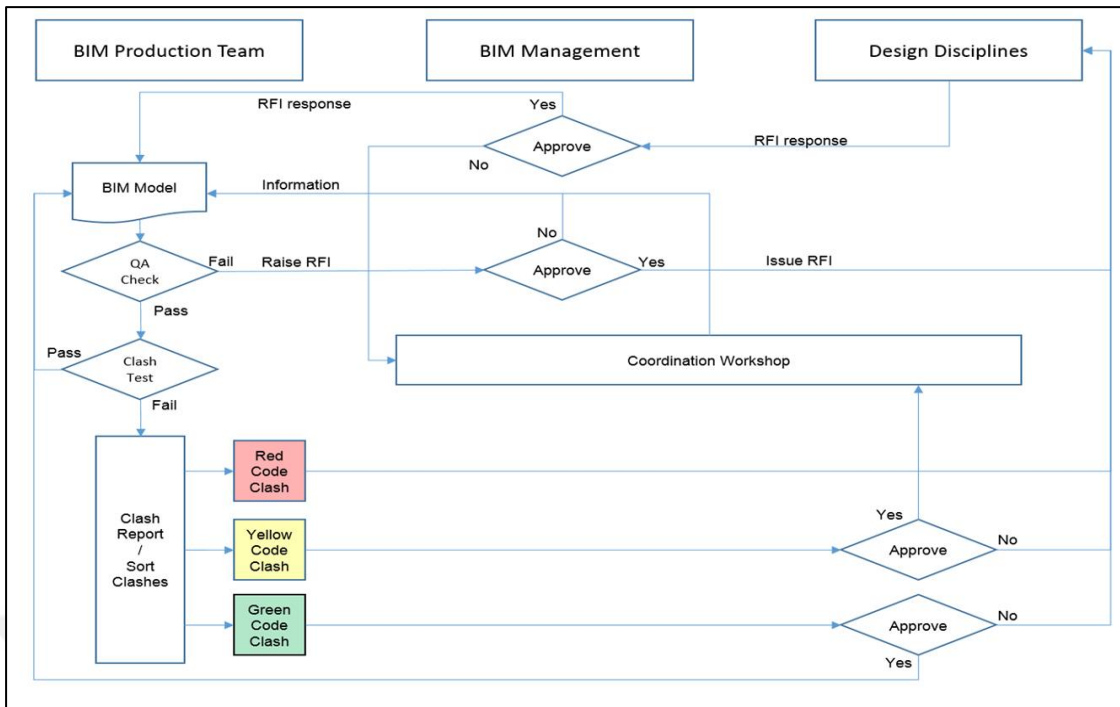
### 4.3.1. Digital Site Engineering

Coordination of all disciplines is extremely hard for Istanbul Airport Project because of its complexity and scale of the Project without using BIM. Architecture, structure, MEP and BHS coordination are not conducted in 2D environment. All clashes between the disciplines are solved with the using navisworks manage software, then clash-free model can be obtained shared with related departments/disciplines in order to progress on site. In Figure 19, BIM centered relation and collaboration between project parties are shown.



**Figure 19.** Communication between Project members using BIM

In the beginning of the project, necessary workflows for key project processes are prepared by the BIM team, in order for ensuring the design to construction delivery is successfully done according to the correctly engineered and coordinated BIM model. In this manner, clash resolution is the first step of a clean, on-time and on-budget construction progress. In Figure 20, clash resolution workflow is shown for Istanbul Airport.



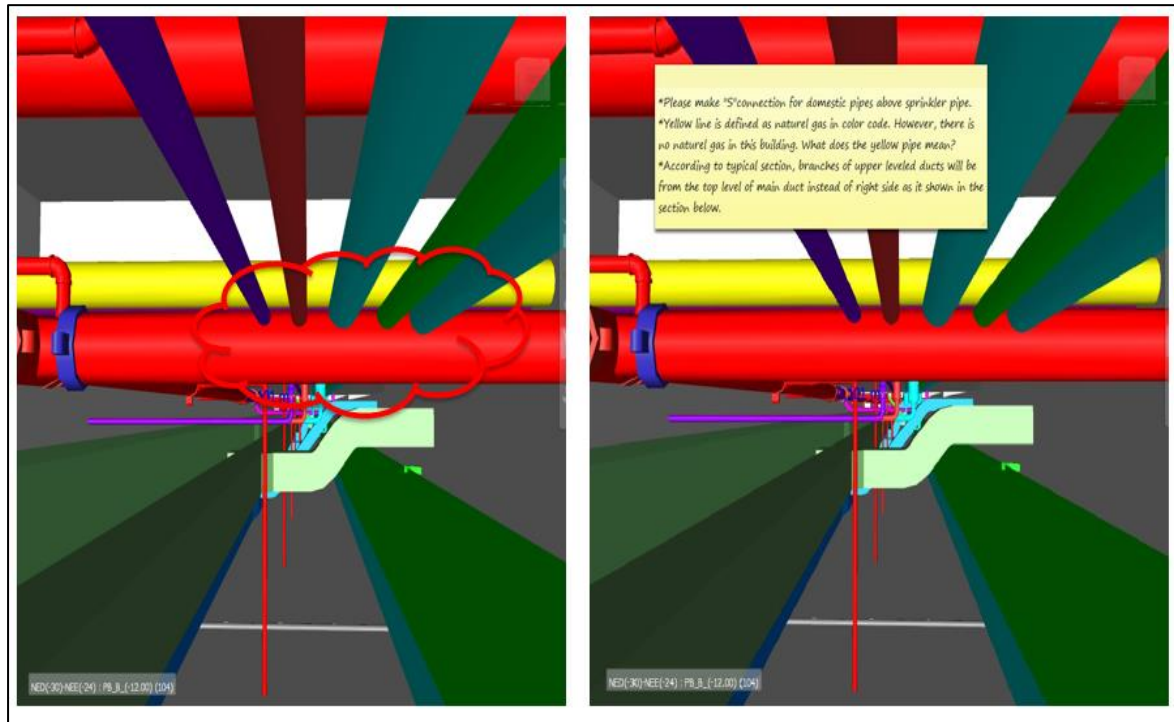
**Figure 20. Clash Resolution Workflow**

Before site installations begin, according to the construction planning, BIM Model is getting clash-free for subcontractors and site teams to rely on a correct model. Clashes are resolved in a structured manner which every step of the process is under record. In Figure-21, a sample MEP vs Architecture clash report can be seen.

20160113_PLUM_VS_ARCH									
Tolerance	Clashes	New	Active	Reviewed	Approved	Resolved	Status		
0.001m	125	0	0	20	85	20	OK		
Image	Clash Name	Status	Distance	Grid Location	Item 1 Path	Item 1 Item Name	Item 2 Path	Item 2 Item Name	BIM Comment IGA / Consultant Comment
	Clash103	Reviewed	-0.022	NED-NEE ; PB_B (-> PB_DR_D (+0.00) > Pipes > 12.00)	INA_PLUM_PB MOCKUP.nwc > Storm Water	Storm Water	File > File > INA_ARCH_PB MOCKUP.nwc > FA_INA_ARCH_P00_FACD_00.rvt : 13 : location Internal > Curtain Panels > FC_AP_EWS_00_RAINSREEN > FC_AP_EWS_01 > FC_AP_EWS_00_RAINSREEN > FC_AP_EWS_01 > Solid	FC_AP_EWS_01	

**Figure 21. MEP-Plumbing vs Architecture Clash Report**

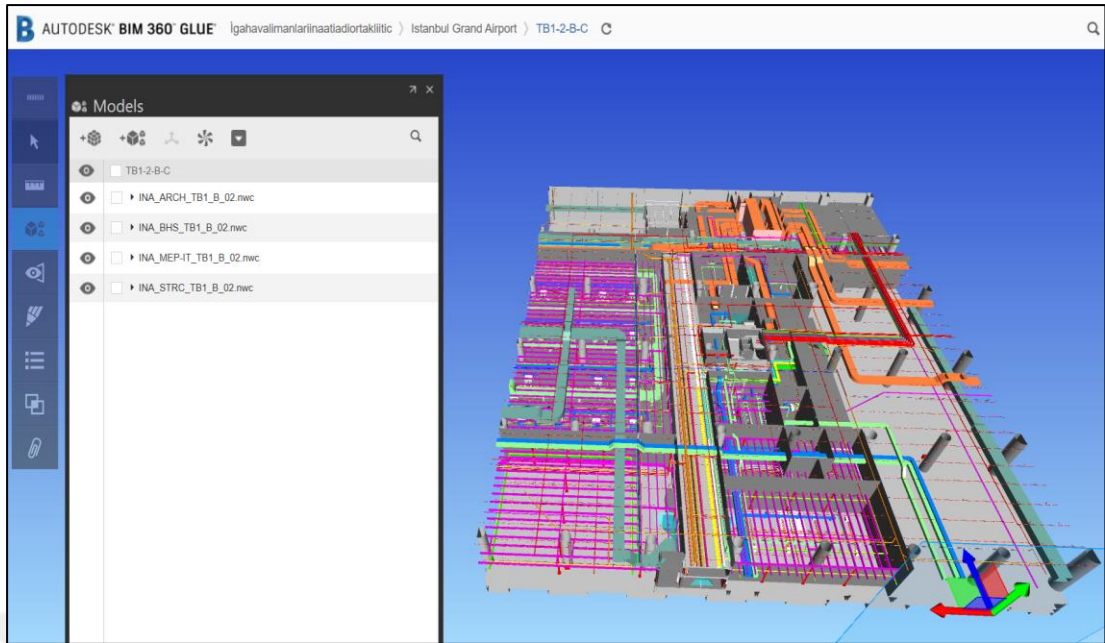
In Figure 22, a sample viewpoint of a clash and clash markup can be seen. These clashes are coordinated between design teams and modelling teams and necessary actions are taken. At some point if there is no re-routing option available, model is used for engineering purposes.



**Figure 22.** Snapshot for MEP Clash Resolution

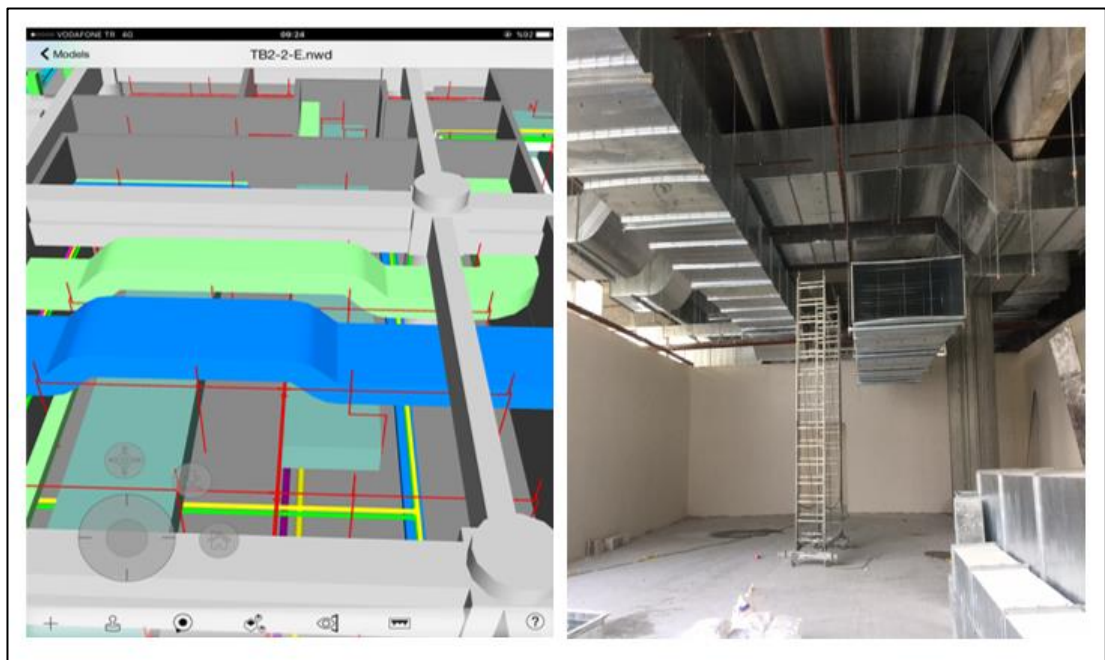
Another helpful application is BIM360 Glue, which enables project teams to access related project knowledge virtually anywhere, wherever, through cloud-based BIM collaboration. BIM 360 Glue provides multi-disciplinary teamwork and coordination analysis cycles to be carried out more efficiently by the project.

All updated layers of each discipline are checked and merged with each other. Then the updated merge models are shared with field for engineers to control the project situation and manufacturing by their tablets on site via BIM360 Glue. A sample view of BIM360 Glue mobile application can be seen in Figure 23.



**Figure 23.** Layers (Arch/Strc/MEP-IT/BHS) and Section of TB1-2-B level in Glue

Site manufacturing and processing are checked by site engineers with the help of shared model in BIM360 glue for all zones. The progress are compared with the updated BIM models in site. An example comparison of site and model can be seen in Figure 24.



**Figure 24.** BIM model vs Site Manufacturing

#### **4.3.2. QA/QC and Project Control**

Technology, QA/QC and the use of technology are also very important, so that a collaborative environment with subcontractors has been developed from the very beginning of the project and mobile tablets have provided this very well on site. Since all engineers are fully equipped with technologies, on a cloud network with BIM360 Area, they can reach the latest project models, making a major contribution to better quality of engineering.

Notification for Inspection (NFI) with QA/QC checklists, approved Shop Drawings (SD), Material Approval Form (MAF), Method of Statements (MS) are stored in BIM360 Field Library. Besides, Test&Commissioning Request (TCR) will be applied over the BIM360 Field for all the equipments which are in site.

All checklists (ITP's-Inspection Test Plan) are prepared by subcontractor and approved by IGA QA/QC team and uploaded the BIM360 platform. NFI is defined with related checklist for site inspection again using the BIM360, then site engineers are conducted the NFI and approved or reject with their tablets on site.

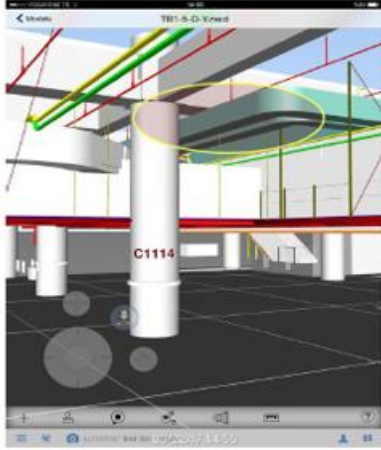
In addition to NFI's, issues and observations(obs.) which have significant impact for site progress are created and checked with BIM360 system. Controls about the observations are conducted by related engineers who are BIM Site engineers and QA/QC engineers. Problems-issues are solved on site by the help of engineers, then the obs is closed. Engineers are also checked Material Approval Form of equipments from the BIM360 library, if there is any problem about the approval form of equipments/materials, observation can be opened by engineers.

An example about BIM Site Engineering Report & QA/QC Report details can be seen in Figure 25.




Istanbul Grand Airport		Issue Report	
Company	IGA	Status	Open
Type	BIM Site Control	Due Date	30 Apr 2017 12:00 AM
Author	[Redacted]	Author's Company	IGA
Date Created	22 Mar 2017 3:17 PM	Root Cause	
Description BIM'e Uyumlu Olmayan HVAC Montajı			
Location Terminal > (0.00) Level D > TB1 > TB1-5			
Location Detail			
Additional Properties for [Redacted]			
Discipline		Mechanical	
BIM Issue		<input type="checkbox"/>	
Comments for ID [Redacted]			
10 Apr 2017 2:52 PM		BIM Model kontrol edilerek modele uyumlu olacak şekilde düzeltilecektir. Koordinasyon sağlanacaktır.	
22 Mar 2017 3:28 PM		Kanallar BIM modeline göre olması gerektiği yerden geçmemektedir.	




2017-03-22 13:55:22



2017-03-22 13:55:53

**Figure 26.** BIM Site Engineering Observation Details on BIM360 Field

These reports are executively reported weekly to the top management of the project in order to provide transparency. There is also a huge benefit of fully digitalized site engineering and QA/QC processes which at every desired point of time, a detailed report for subcontractor performances on site can be derived from the system. It can even be automatically created and delivered to the desired e-mails of project responsables, weekly or monthly. Observations status summary created by BIM360 Field system, a sample can be seen in Figure 27. This reports are shared with other disciplines responsables in order for everyone to see the latest situation and progress periodically.

Istanbul Grand Airport		OBSERVATION STATUS SUMMARY						
All QA-QC Observation Status Summary							2.6.2017	
Company	Draft	Open	Work Completed	Closed	Total Transaction	Past Due	% Complete	
A	2	254	24	323	605	159	53,4 %	
B	104	61	2	8	175	14	4,6 %	
C	0	43	0	17	60	41	28,3 %	
D	0	20	0	41	61	1	67,2 %	
E	1	15	2	40	58	8	69,0 %	
F	0	5	1	22	28	0	78,6 %	
G	0	5	0	2	8	4	25,0 %	
<b>Total for all companies</b>	125	612	30	613	1383	291	44,3 %	

*Figure 27. QA/QC Observation Status Summary*

#### 4.3.3. 4D BIM to Schedule

Planning is very crucial step for the big scale construction Project. There are thounds of activities and Works to achieve and every delays in the Project can be affected drastically the finish date. BIM provides detailed overview of components and activities can be planned in accordance with BIM. Easier scheduling due to the information which is available on BIM platform are occured. Besides, 4D simulation can be created with the help of planning in BIM environment. Visualization provides better activity sequencing. Better workflow, efficient construction process with reduced waste production can be achieved.

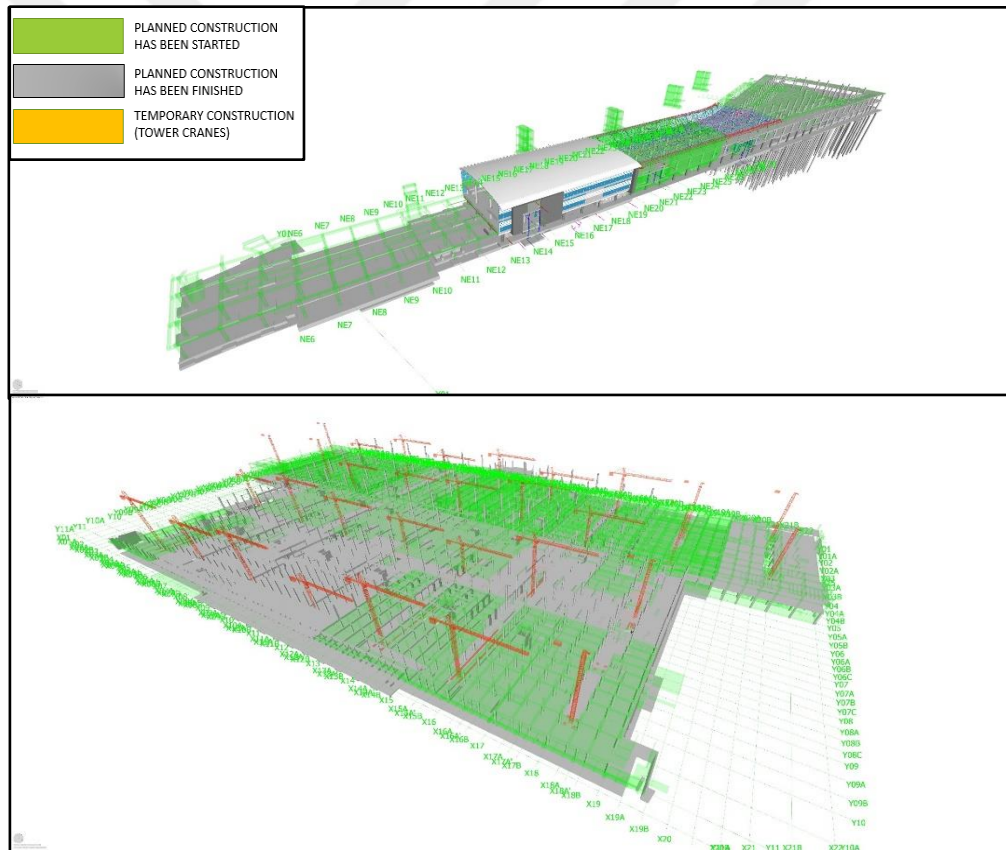
A 3D model is combined with time by integrating construction Schedule to form 4D modeling to create simulations for construction activities. In order to demonstrate the progression of development over time, the models integrate building elements with construction activities; 3D models are connected to particular activities that can appear or disappear according to the schedule at specified times. During the construction time, permanent building features that are to be built emerge and remain for the remainder of the schedule. Temporary spaces/objects, such as swing space or construction supports, only appear for a specified duration and then disappear. Some advantages are shown in Table 5.

**Table 5.** Advantages of 4D BIM Modeling for IGA Project

Advantages of 4D BIM Model

Smart 3D model linked with construction scedule
Construction Schedule visualized simulation
Monitoring project progress
Planned versus actual comparison
Executive decision making

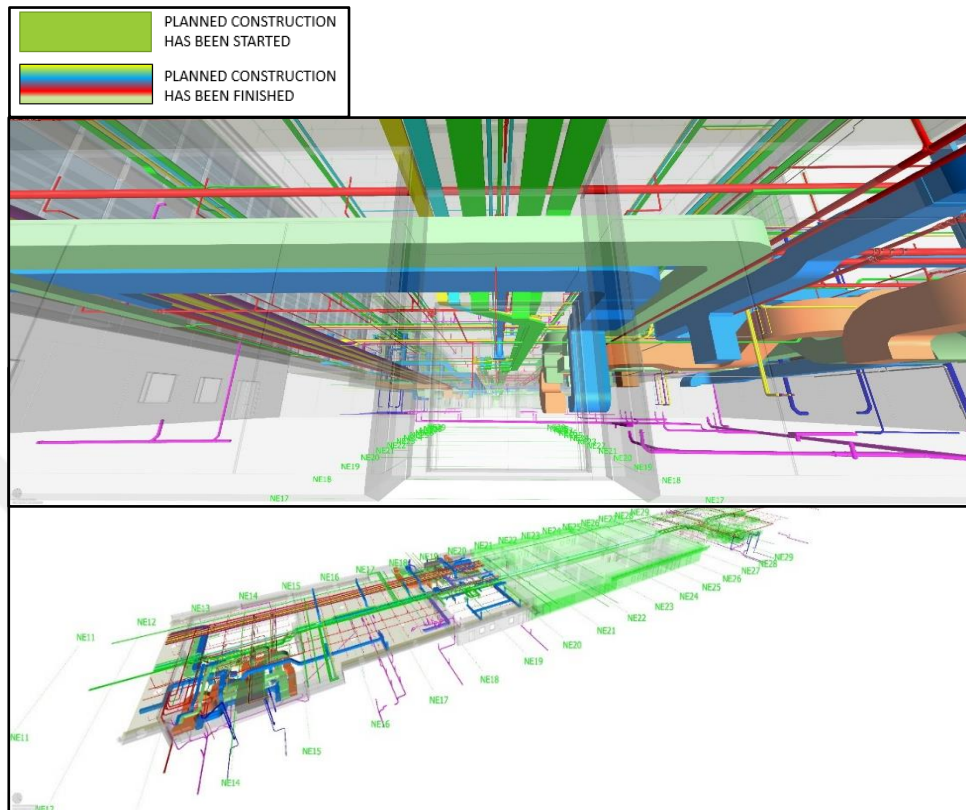
Examples of 4D simulation Master Model snapshots are seen in the Figure 28 with the date of 08.08.2016.



**Figure 28:** Terminal and Pier-1 Sample 4D Model View

4D Model is integrated not only for structural and architectural elements, but also MEP-IT and BHS systems all the activities are linked to the BIM model to obtain a simulation for those disciplines. In Figure 29, a sample view from Pier-1 Level D of

the Terminal Building for planned construction start and finish simulation can be seen in a screenshot of the 4D model.



**Figure 29:** Pier-1 Level D-General Views from 4D BIM Model

The IGA BIM executives notes that time and cost estimation provides better understanding of construction documents in terms of job sequencing and helps with executive level site planning.

#### **4.4. BIM for Sustainability**

İstanbul Airport Project includes a Terminal Building of 950.000 m<sup>2</sup> and Pier Buildings of 320.000 m<sup>2</sup> that require an efficient energy analysis. Therefore, the implementation of BIM in the project offers many possibilities by providing easy access from a single digital platform to all project data, including 3D models at different LODs, 2D drawings, and all supplementary documents, and also allowing quick modification or updating of data whenever appropriate, thus minimizing great waste of time and expense. As a summary, following points can be given as benefits of BIM for sustainability;

- Energy modelling, detailed analysis of energy needs of the structure and analysis of renewable energy options such as solar energy.
- Building orientation providing best building orientation option that leads to minimum energy cost.
- Reducing time and expenses for energy analysis allowing change of many design parameters fast.
- Access to recent data for unit energy costs and weather via using an internet server.

Green Building Studio(GBS) and Insight 360 are used for energy analysis in the Project. Revit 2016 & 2017 versions are suitable for using Insight 360 which works in an integrated fashion with GBS server.

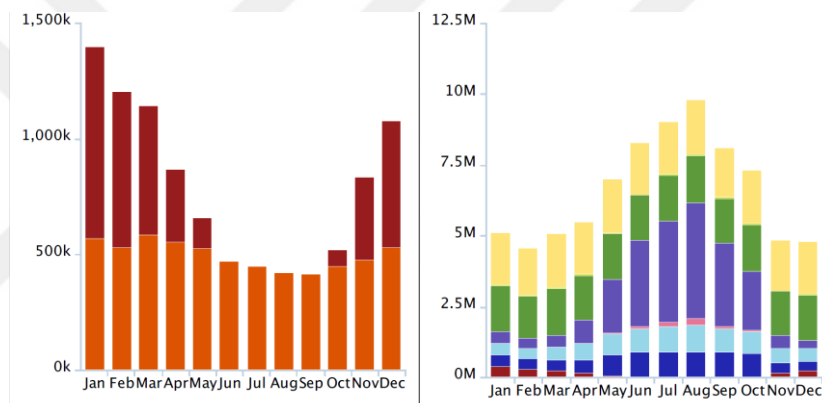
*Green Building Studio (GBS)*: It is a web-based energy analysis service that helps users early in the design stage to determine the environmental effect of individual building components. Primary analysis capabilities of the program include energy and thermal analysis, analysis of lighting and shading, and analysis of value/cost. Energy/thermal analysis assesses the consumption of energy, carbon emissions, ventilation and airflow. Lifecycle evaluations and lifecycle costs are determined by the value and price functions.

*Insight 360*: Current workflows including Revit Energy Analysis and Lighting Analysis for Revit are incorporated by Insight 360. In addition to understanding PV energy output and saving and comparing design scenarios to monitor performance spanning the construction lifecycle, it enables simulation of solar radiation on mass or building element surfaces with new solar analysis workflows.

All analysis conducted with GBS and Insight 360 with the help of Revit 2016 software for;

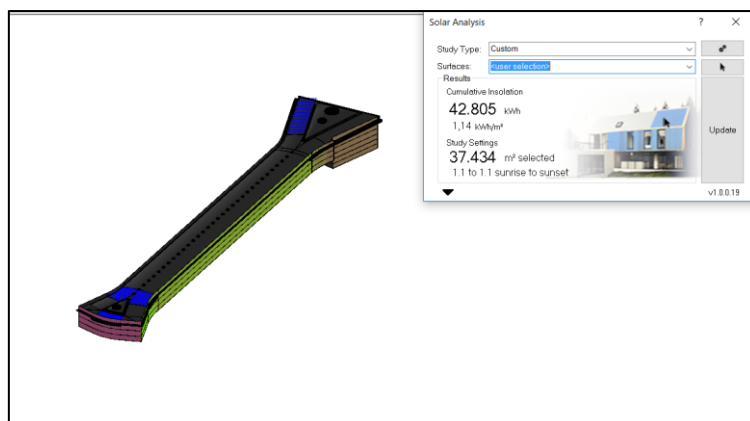
- Terminal 1- TB1 - (all levels )
- Terminal 2 + Terminal 3- TB2&3 - (all levels)
- Pier 1- Pier 2 – PB1&2 - (all levels)
- Pier 3-Pier 4- PB3&4 - (all levels)
- Pier 5 – PB5- (all levels)

And sustainability analysis can be obtained at the end of the process. According to end value of Sustainability Analysis, Via a decent optimization and project defaults assumptions and determinations, it has succeeded to analyze all Terminal and Pier Buildings and found annual and monthly data –both in energy units and in monetary units- of total energy. In means of energy, annual and monthly monetary and energy equivalents of space heating, space cooling, area lighting, hot water supplies have been generated graphically which enables us to foresee future energy consumption of airport buildings. Furthermore, the iterative data we get from the energy analysis process will lead us to take retrofiting decisions in the design of the airport. Overall, with the implementation of sustainability analysis, İGA are executing the application of 6D of BIM. Having considered this, please check the following sample outputs taken from GBS dashboard (Figure 30).



**Figure 30:** Energy Cost in Energy Units & Energy Cost in Monetary Units

Lastly, solar analysis result sample of a single Pier of Istanbul Airport is given in Figure 31 visually.

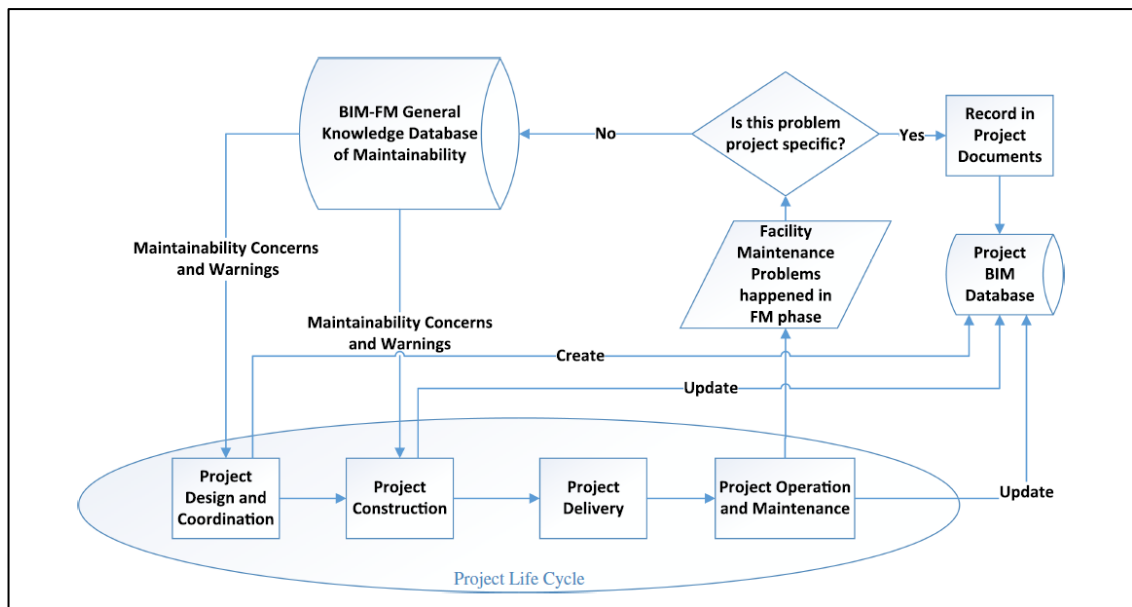


**Figure 31:** Solar analysis result of PB5 building

#### **4.5. Facility Management with BIM**

It is one of the key objectives of extending Istanbul Airport's life-cycle efficiency and sustainability by using BIM in the next phases for facility management and operations. Facility documentation integrated in the BIM model and BIM model is handed over to clients for their facility management. The handover was seamless and data loss was minimum since BIM has been used in all project phases including design and construction. Exceptional visualization and reporting capabilities of BIM platform was beneficial during the commissioning to handover stages of equipments.

As defined by Cotts et al. (2009, quoted in Arayici, Onyenobi & Egbu, 2012), Facilities Management is a "multi-disciplinary field comprising multi-disciplines to ensure the functionality of the built environment through the integration of people, location, process and technology." The BIM methodology explains the use of BIM tools and techniques to strengthen the conventional business process and add value to projects. (McGraw-Hill 2012). Planning, design, construction, facility maintenance and operations are included in the BIM processes. The possibilities for using BIM for facility operations are convincing, but in the design and development stages, the application of BIM for facility management lags behind BIM adoption (Akcemete et al. 2010). A analysis by the U.S. The National Institute of Standards and Technology (NIST) has shown that the annual cost of insufficient information system interoperability is \$15.8 billion (Gallaher et al. 2004). As a consequence of continuous facility operation and maintenance operations, two-thirds of this expense was generated (Shen et al. 2010). This concern occurs because knowledge has to be collected repeatedly at multiple points. In the use of BIM, data can be captured only and used during the life cycle of the facility. In comparison, at an earlier level, certain maintenance issues are much simpler to fix and cost less. While BIM is designed to be a shared platform, communication databases do exist in practice. In order to reach a consensus on BIM-FM practice, a bridge should also be built to close the distance. The experience and knowledge required to implement BIM for FM are missing in many facility managers; designers and architects are not aware about what FM data should be collected and what FM requirements should be taken into account in their BIM activities. (Liu 2012; Liu and Issa 2013b). A knowledge workflow for project lifecycle is given in Figure 32 for facility management implementation that shows maintainability issues in BIM implementation.



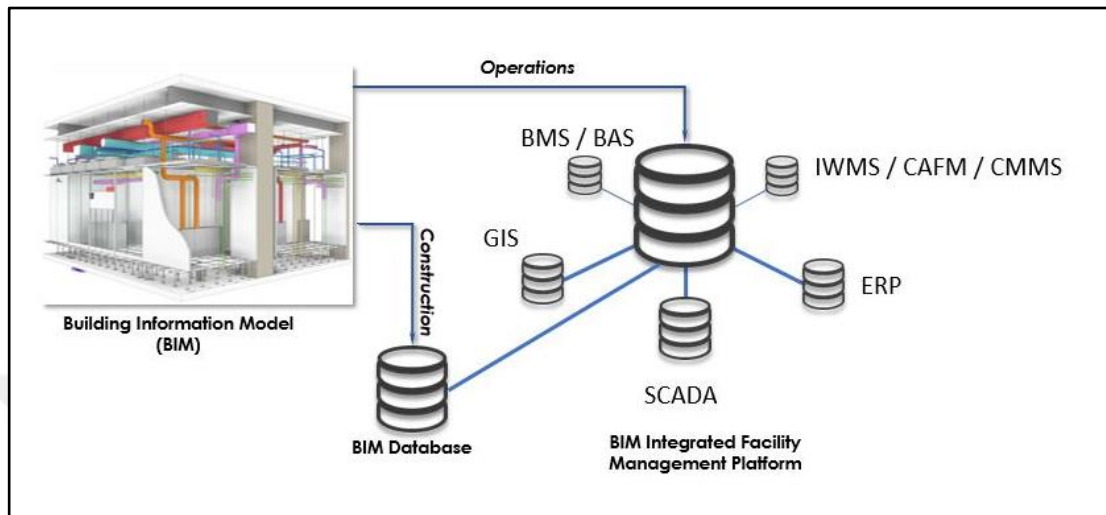
**Figure 32.** Knowledge database for maintainability issues (adapted from Liu & Issa, 2013a)

In IGA, the aim is to connect various databases with existing BIM database which includes visual and non-visual data. In aviation, measurement is very crucial for management, in most of the operational aspects of the industry. Aircraft, people and bags must be moving all the time and a great passenger experience shall be maximized through the highest utilization of technology and people as possible.

BIM and SEM (Service Execution Management) interface is also an important integration in order for effective field service management. An integration between BIM and Service Execution drives an efficient and profitable 25 years operation for Istanbul Airport. BIM uses a database infrastructure to encapsulate designed facilities with relevant data generated by stakeholders (Arayici et al., 2012). Service execution is one of the integration areas and shall have a separate database to work in integration with BIM.

FM is a multidisciplinary field that integrates entities, place, procedure and technology to ensure that the built environment Works (Cotts et al., 2009; Arayici et al., 2012). The role of FM therefore transcends maintenance management, but also includes emergency preparedness, communication, business continuity, human factors, environmental management and leadership in sustainability, finance and business, strategy, project management, performance, land and property management and

technology (IFMA, 2016). There are many databases that can be integrated with BIM to work seamlessly and controlled over a single dashboard. Those databases can be listed as IWMS, CAFM, CMMS, BMS, BAS, SCADA, GIS and ERP systems (Figure 33).



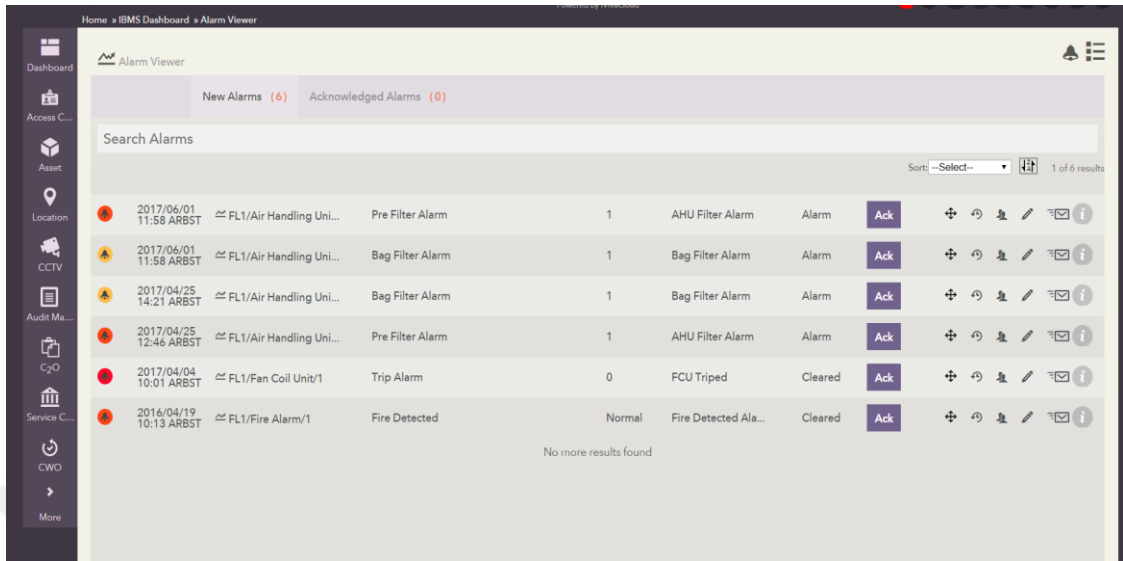
**Figure 33.** BIM - FM Database Integration

It is safe to say that the construction sector has changed over the past couple of decades. As the equipment being used in offices and on sites is more sophisticated than ever before, technology has a lot to do with this.

As BIM technology advances and is used over its life cycles to enhance asset management, asset owners will need to fully understand the knowledge required after completion of construction and the relationship between BIM, asset management and maintenance management systems.

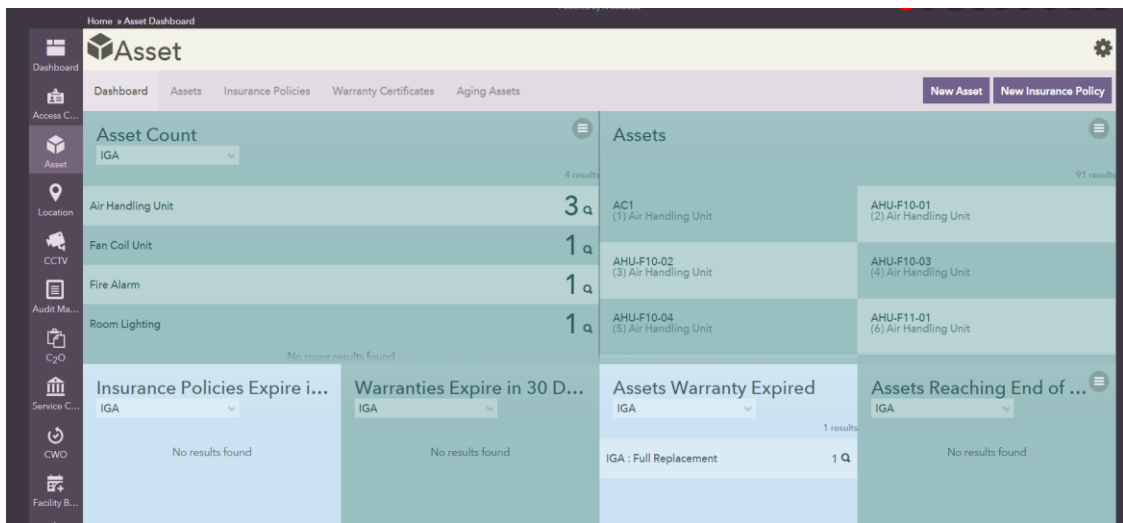
IGA has partnered with an outsourced organization specialized in the design, development and deployment of smart workplace solutions, which is a multinational software solutions provider. The company is considered as a provider of facility management applications for operation & maintenance stages. The company has a cloud for each specific project and management services are provided by their cloud system. However, it is optional to deploy the software and keep all the data in local servers. In IGA, local servers are used for software deployment. They have prepared a demo to show how the integration of databases and facility management implementation process can be conducted with a single dashboard which is deployed

in local server in Airport Data Center. A screenshot for alarm viewer dashboard for facility operations can be seen in Figure 34.



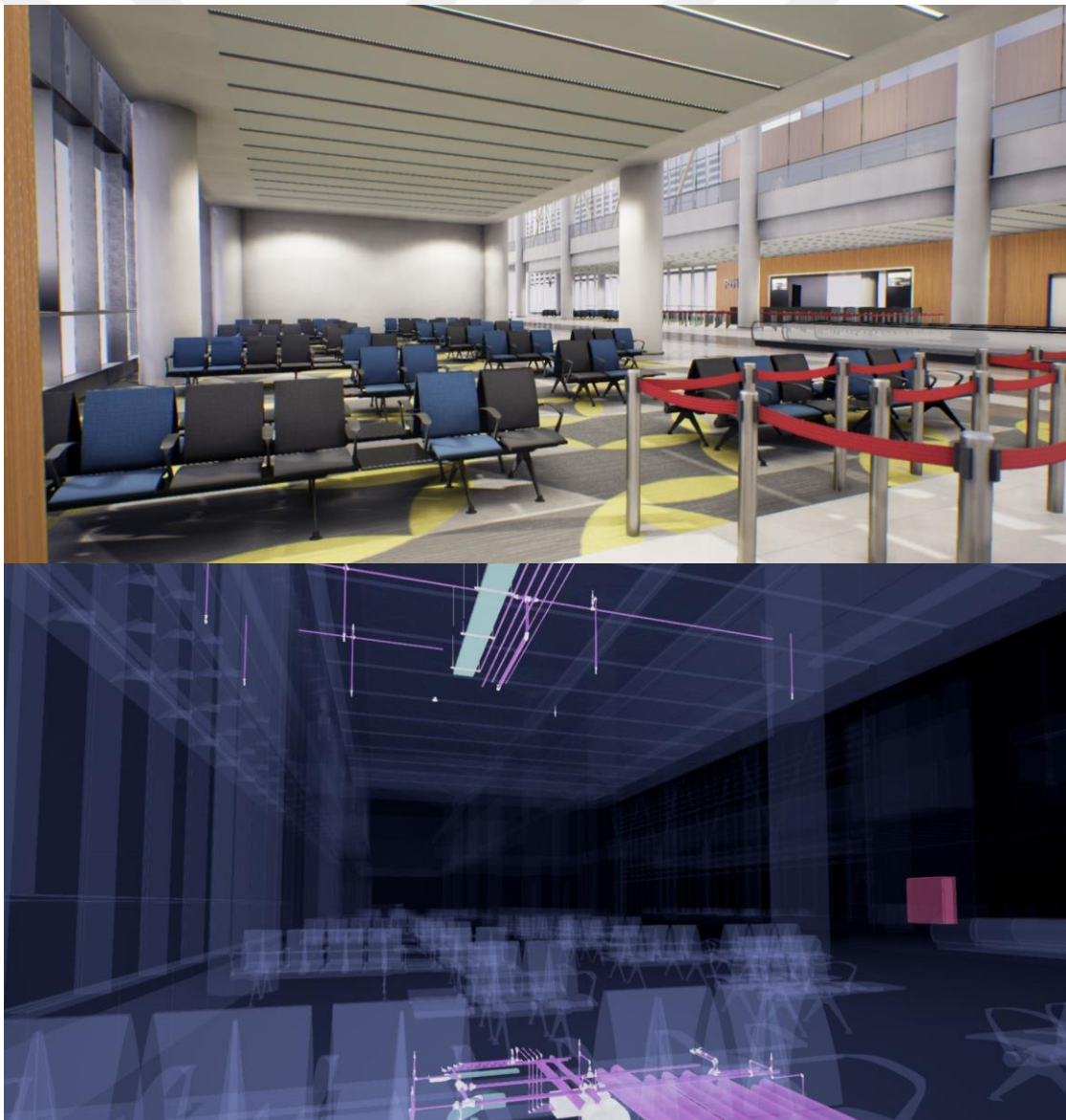
**Figure 34.** Alarm viewer dashboard for Facility Management & Operations

There is also a sample view of demo dashboard for assets in Figure 35. Assets can be tracked and managed through this smart platform fully integrated with BIM model.



**Figure 35.** Assets dashboard for Facility Management & Operations

BIM for facility management provides visualization and access to the accurate location. Therefore, relationship of building systems and equipments/materials can be accessible in an easy way to observe the conditions. In addition to this, BIM provides several benefits over traditional 2D drawings in terms of facility management and operations. BIM objects contain the information of what they are and where they are located. Integrated tools identify areas service that are supplied by which components. For instance, mechanical room 1 and 2 are supplied by Air Handling Unit A or electrical room 7 and 8 are supplied from circuit panel S-2. This information shall provide more flexibility to technical staff over controlling the systems and identifying problems. Sample views of integrated BIM model for facility management software can be seen in Figure 36.



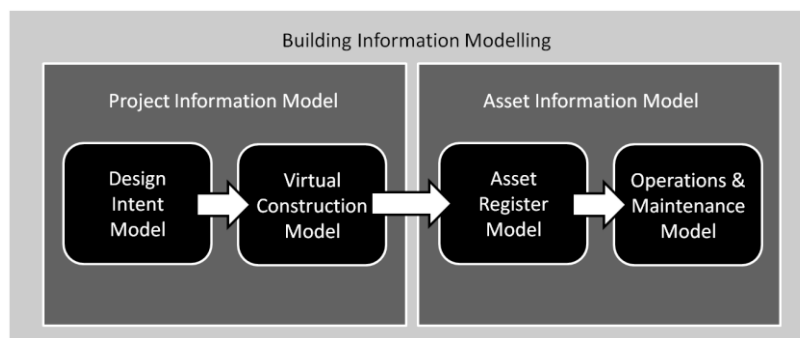
**Figure 36.** Facility management sample model

## 4.6. Construction to Operations Delivery

In Istanbul Airport project, a development strategy in a timely manner has been applied in terms of BIM model development. Together with the development of the BIM model, successful data handover has a crucial role on delivering necessary and validated data to the next phase of the project. Two main topics for successful project delivery from construction to operations are the BIM Model Development and BIM Model Validation processes. Accordingly, integration of the Facility Management platform also called as virtual platform will be examined in the following topics.

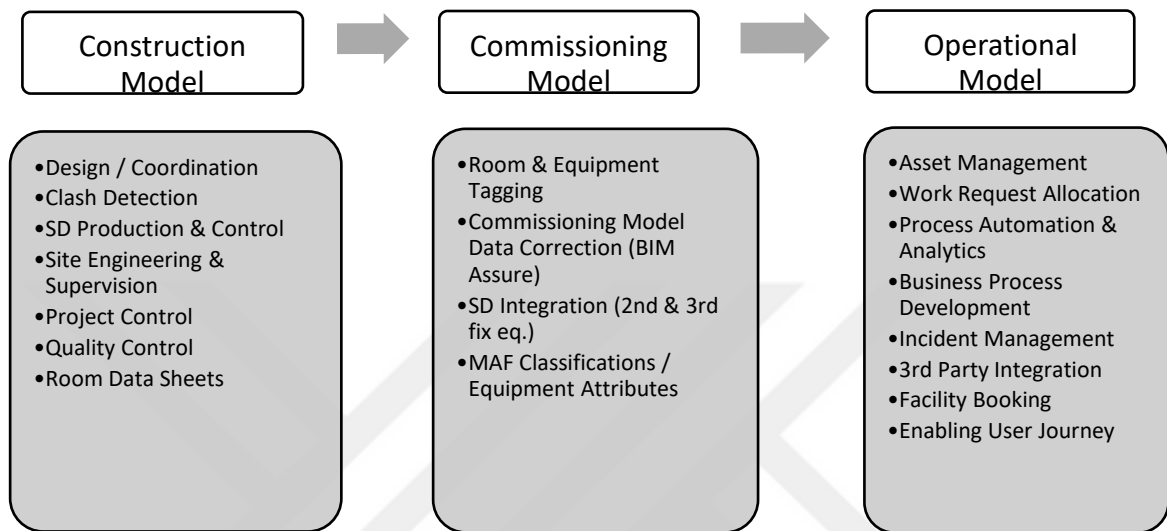
### 4.6.1. BIM Model Development

In a multi-million meter squared and complex airport project with a 42-months tight all included design and construction schedule, there is a very crucial need for a perfect planning in terms of every aspect including design delivery, fabrication, site installations, procurement, shareholder management, information management and data handover. This is exclusively possible with the correct application and strategical approach to a successful BIM implementation across the whole project. BIM Model development is essential to achieve this successful implementation. It is required for the project to take a logical route for modelling, especially by setting the balance between the design management and the construction Schedule. IGA created the modelling strategy parallel with the construction schedule, where design and construction were ongoing at the same time, this is even more important. The basic idea is to feed the project only with the necessary data, at any time of the project. In short, it is about delivering the data point-blank. There is two main model definitions in general. As seen in the Figure 37, a generalisation shall be made for two main stages, project information and asset information model, as compatible with ISO19650-2:2018.



*Figure 37 Generalised Model Development*

The BIM Model Development of IGA is a part of this challenge. Since the main approach in IGA is to adopt the “plan, simplify and execute“, the model phasing is broken up to three main steps which are construction model, commissioning model and operational model. Each of these model phases contain only necessary data for each project phase. In Figure 38, BIM Model Phases and their details are given.



*Figure 38: IGA BIM Model Phases*

Between each transition of the model phases, there is a structured planning for additional data entry to the model, in order to execute necessary workflows for every project phase. Owners system classification, asset type, asset category, unique ID, manufacturer, parts number, installation date Floor, location, room, warranty information, maintenance frequency, supplier, expected life, costNaming conventions; Omniclass for materials are used.

IGA BIM and technical departments collaboratively worked together to agree on the necessary attribute data for equipments to be populated in the model database.

#### **4.6.1.1.BIM Model Validation**

Quality checking for the existing BIM model is very critical for successful handover and efficient use of the model in post-handover phase. Aligning the asset information with the current stage of the project is a key factor to create a correct BIM model for operational uses.

#### 4.6.1.1.1. Validation of Non-Graphical Data

In order to validate data, a software for BIM Model validation is used to ensure any misinformation or defects in the model are corrected in IGA.

As seen in the workflow given in Figure 39, BIM Models are synched from Revit to validation software directly in cloud environment with an add-in inside the Revit. When models are reviewed in the software platform, they are checked with rules that have been created by IGA to match the project requirements and pre-defined attribute information.

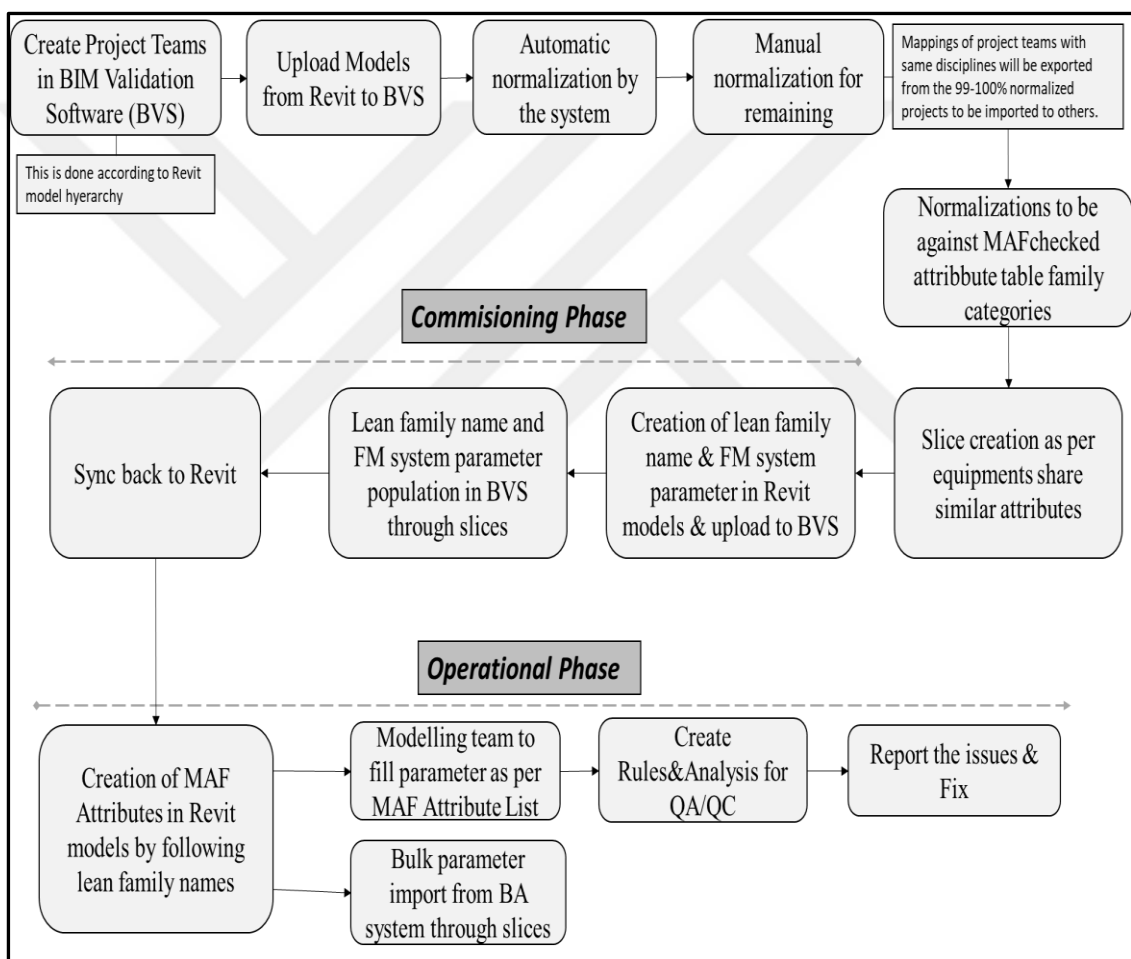
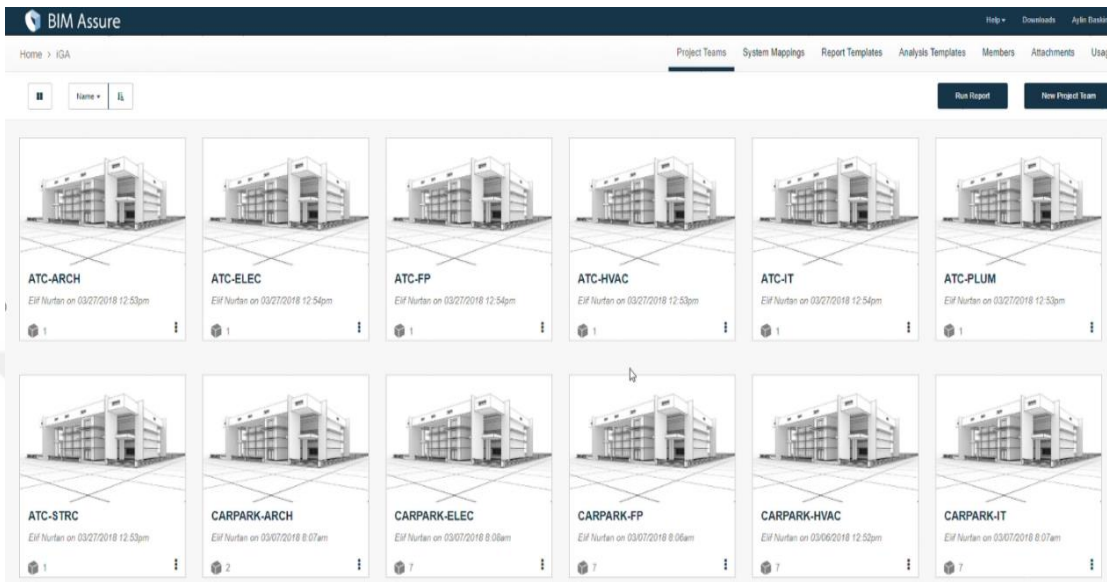


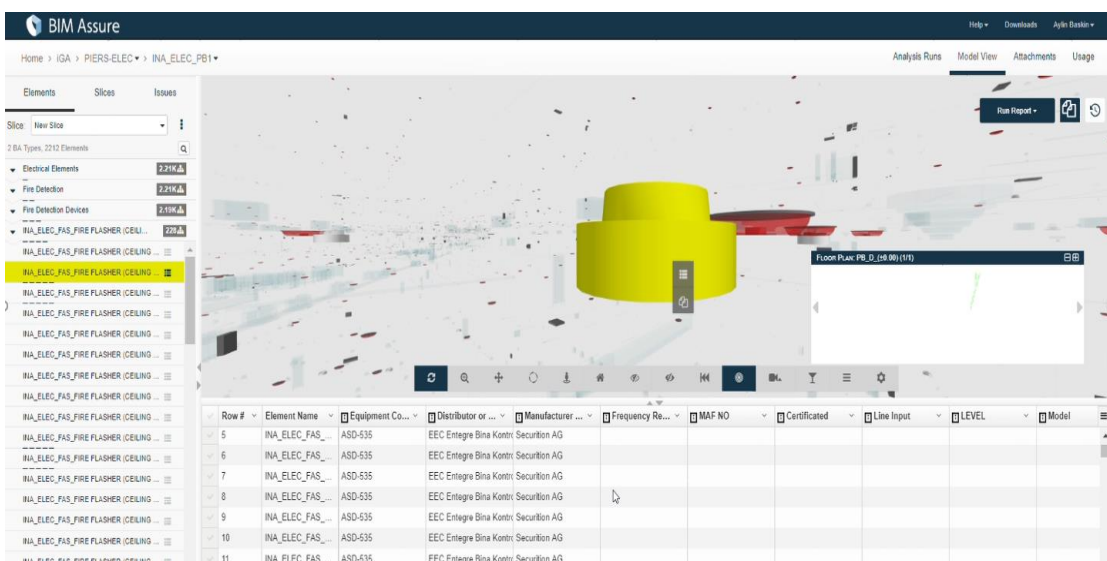
Figure 39. BIM Model Validation Workflow (Source: IGA)

Models are populated asset by asset and discipline by discipline in the software platform as seen in the screenshot in Figure 40. Once the models are checked by the rules created, results are exported to an excel report and reports are reviewed to update and revise the models. This processes can also be followed through the software platform dashboard.



**Figure 40.** Rule based QC Check for Equipment and object attributes

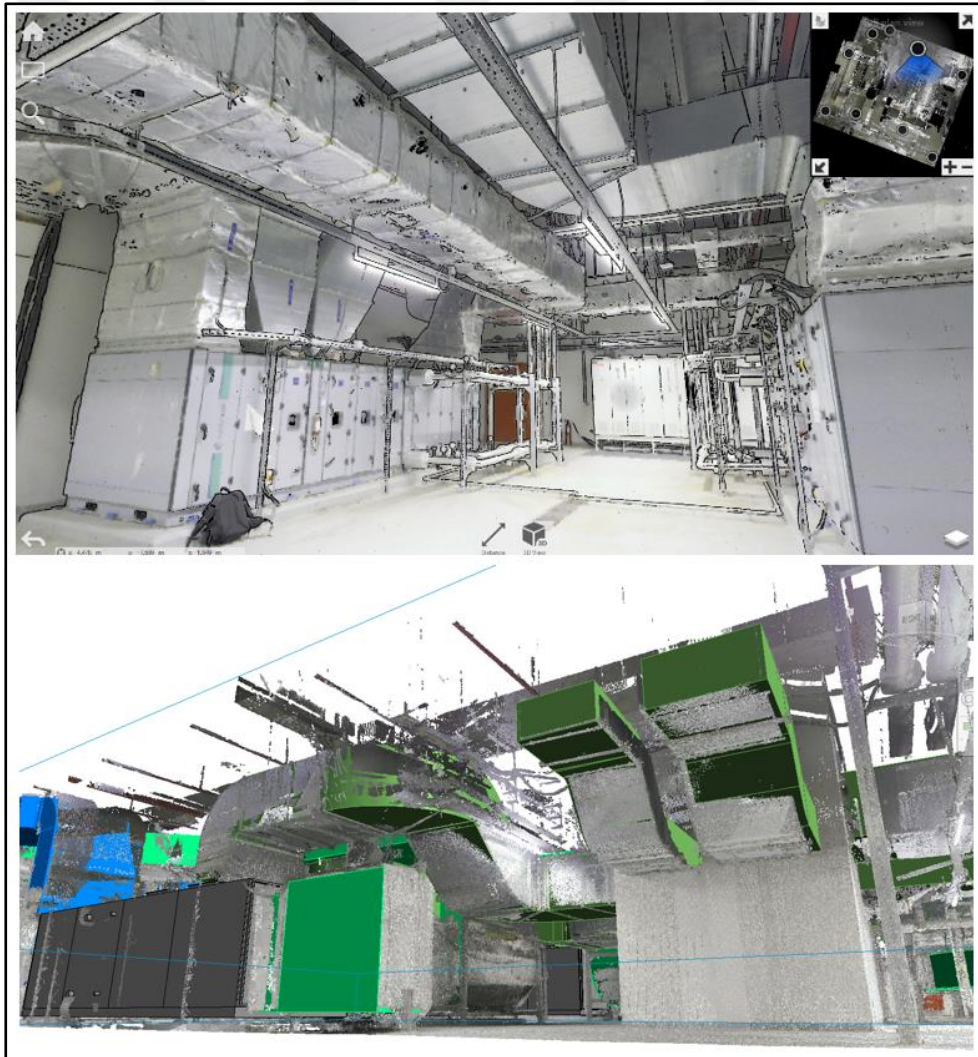
All equipments can be grouped and filtered by rules for data validation as seen in Figure 41. Checking BIM models on time for collaborative data validation is the key for a successful handover of information that owner and facility management teams need. This is achieved by creating a structured workflows for quality checking for the necessary data in the model.



**Figure 41.** Revit Models Synched with Validation Software

#### 4.6.1.1.2. Validation of Graphical Data

High compatibility of site installations with the BIM model is achieved by full implementation of BIM in design and construction processes in IGA. Creating a fully engineered and clash-free coordination model and delivering the model for fabrication and site installations together with digital QA-QC and commissioning, almost every defect and non-conformancy is under record. However, for full confidence of graphical accuracy in the operational phase, validation of the model objects are done for technical rooms by using a laser scanner to gather point clouds with the ease of mobile applications. In Figure 42, a view of a point cloud from Autodesk Recap and point cloud embedded Revit Model can be seen. As seen in the view, BIM model is validated to ensure the model is as-built and fully compatible with the site conditions.



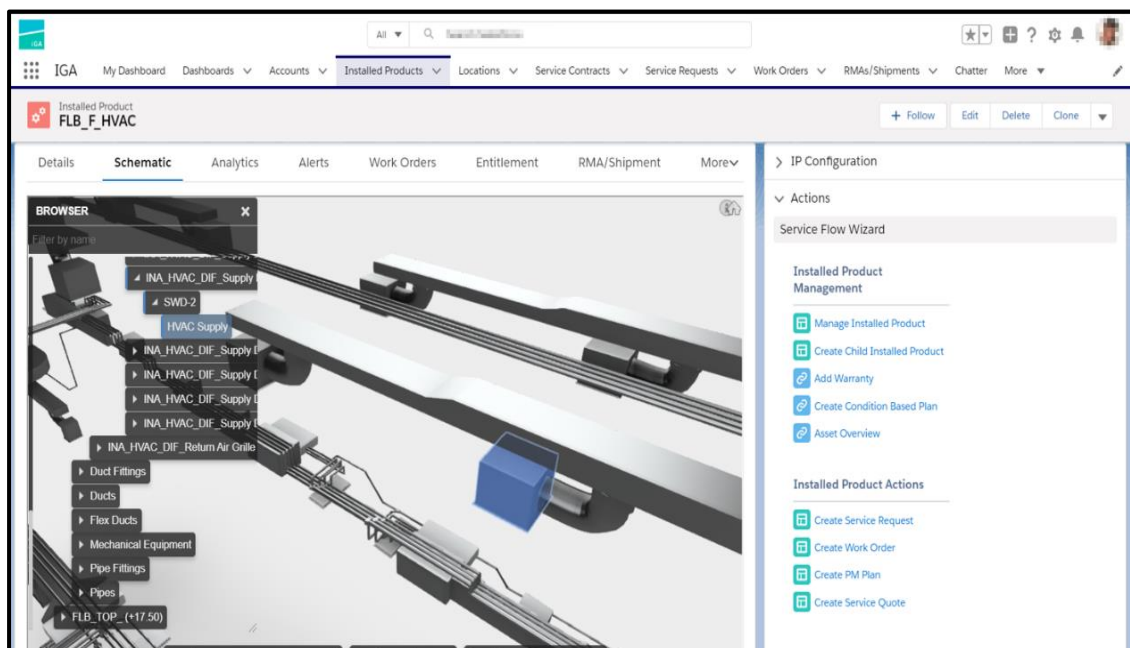
**Figure 42.** ReCap view of a mechanical room point cloud (above), point cloud embedded Revit Model (below) (Source: IGA)

BIM Team captured the real as-built and commissioned environment and created point clouds after a registration period for all mechanical rooms. Raw data of point clouds after first registration was exported to Autodesk Recap for second registration and indexing in order for them to be embedded in Revit Models in true coordinates for validating object locations, sizes and possible additional objects. Other technical rooms including electrical and ICT is planned to be scanned.

#### 4.6.1.2. Virtual Platform Integration

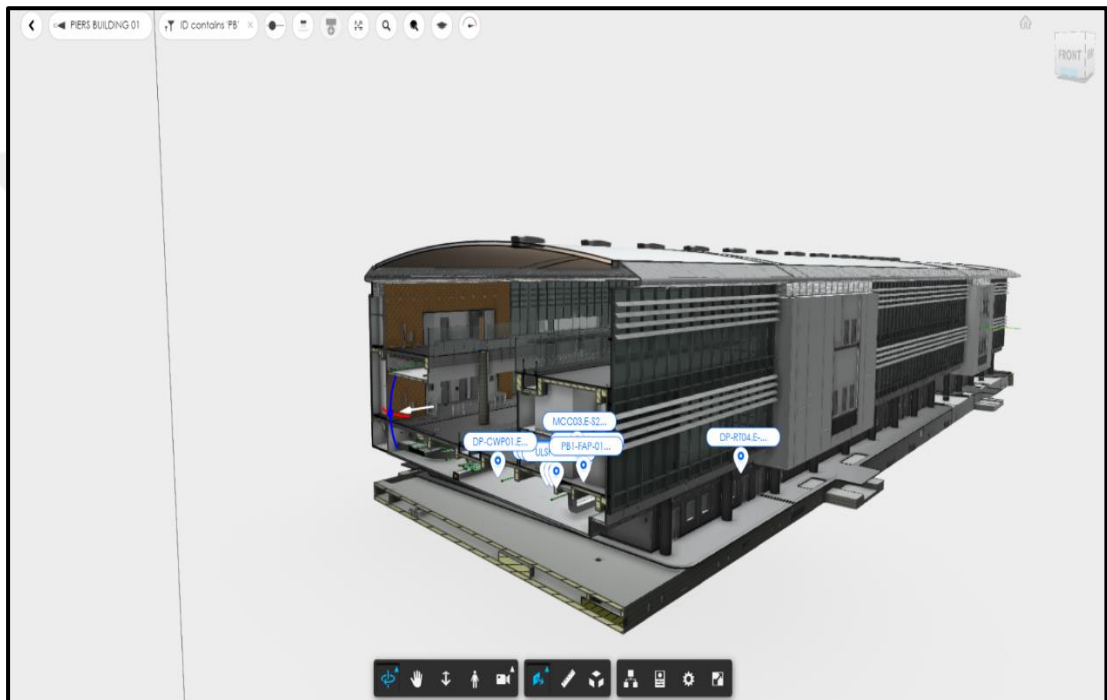
A virtual platform can be established to connect various databases such as BIM, GIS, ERP, IWMS, CMMS, CAFM, BAS, BMS. Using the BIM model for facility operations brings Digital Twin term into the industry which the virtual environment represents the real world and enables various operations to be done efficiently and effectively. Digital Twins are open to many opportunities to bring business value by increasing efficiency, time and cost savings and better supply chain management.

In IGA, several demo platforms were prepared for showcasing and testing of digital twin integration into facility operations. A specification has been prepared by involving various departments of the airport management including procurement, technical services, inventory management, finance and so on. A sample screenshot of the virtual platform demo including BIM model integration in asset lifecycle management and work order management can be seen in Figure 43.



**Figure 43.** Virtual Platform Demo for BIM Model Integration for FM

It is possible to integrate BMS system to exchange real-time data of equipments by sensors, enabling the user journeys and operational ease for work order management and incident management. A sample view of an operation center dashboard of a Pier Building together with various asset and alarm pins attached can be seen in Figure 44. With the ease of model navigation, it is possible to reach any graphical or non-graphical information of an asset, control over the asset and dispatch technical staff for maintenance.



**Figure 44.** Virtual operation center dashboard demo for a Pier Building

## CHAPTER 5

### RESULTS AND FINDINGS

In this section of the thesis, overall outcomes of the research resulting from the literature review and case study are showcased. These outcomes include a framework for BIM based smart facility management embracing the BIM implementation processes from the beginning of a building lifecycle to smart process management in operational phase of a building. As a result of a qualitative approach for data collection and direct participation of the researcher to the project subject to the case study and bringing straight-forward experience for the research, data analysis is resulted with this framework. Together with the framework, benefits of BIM usage for construction phase and potentially for facility management phase of a building is explained.

During design and development, BIM has proved its worth, some owners still see the possible benefits of integrating BIM model data into facilities management systems. Early adopters of BIM for facilities management are seeing a range of benefits, from eliminating the need for reentry of equipment-related data into current FM systems to creating more model-based virtual environments for preparation and implementation of operations and maintenance activities. (McGraw Hill, 2014). The end purpose of a BIM model is to use it in FM, whether the building is new or an old one, which will significantly minimize the expense of the facility life cycle (Edirisinghe et. Al, 2017)

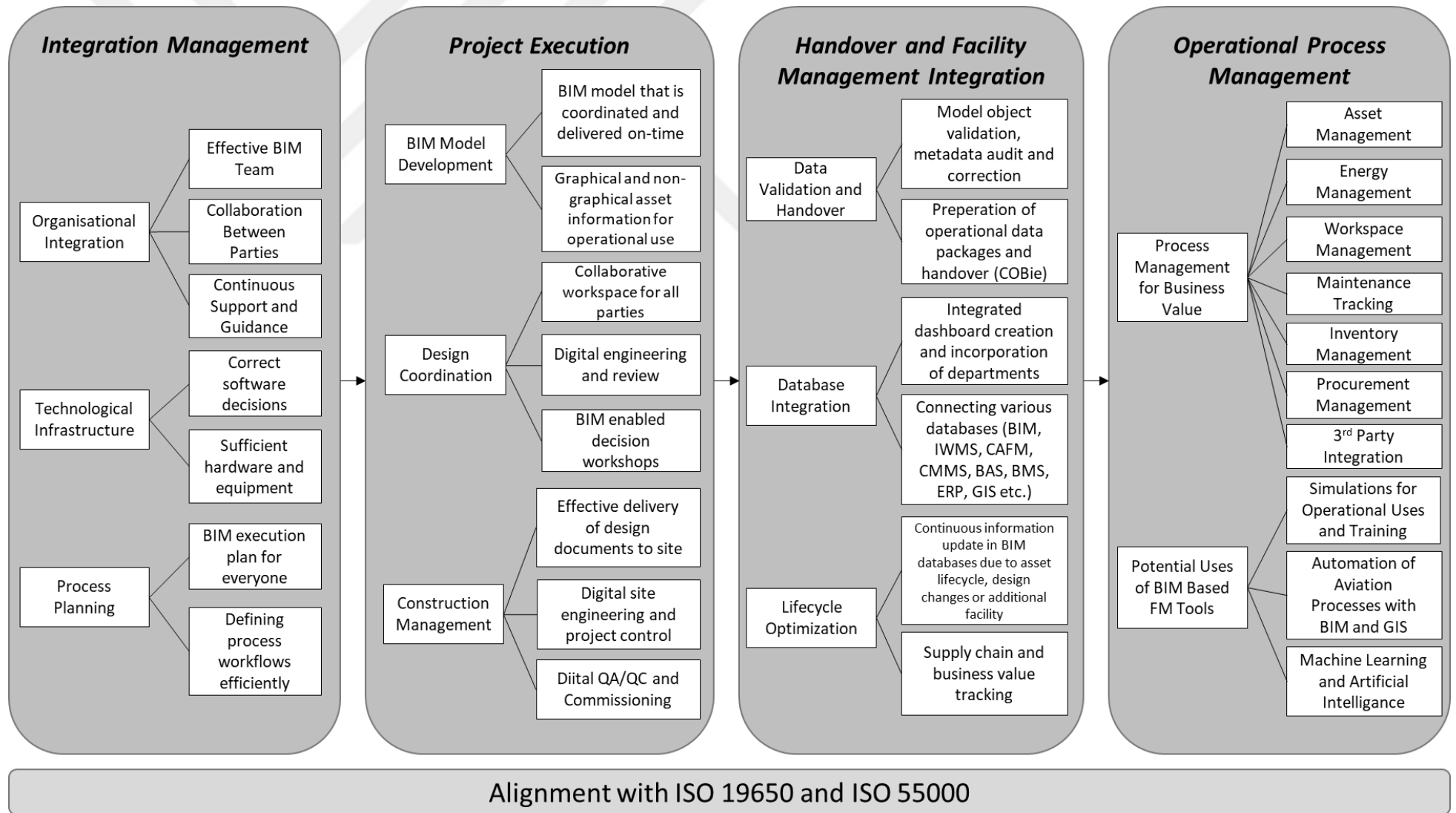
#### **5.1.Framework Development**

In consideration of the research objectives, it is necessary to establish a framework for overall BIM integration and project execution, which is necessary for creating an effective BIM database for operational use. A framework is established with a step by step approach including both processes and methodologies given in a structured manner to explain BIM based project delivery and facility management (Figure 45). This can also be seen as a roadmap for BIM implementation especially for projects with high complexity or relatively larger projects which generally involves thousands of people in the lifecycle of the building. Hence, this framework can also be seen as a guidance for any kind of construction project which BIM is to be used to some degree. In the framework there are four sections including Integration Management, Project

Execution, Handover and Facility Management Integration and Operational Process Management. These sections are explained in detail in the following topics.

Further research and review of industry practices shall be done to develop this framework for overall improvement and increase of the business value.





**Figure 45.** A Framework for BIM Based Smart Facility Management

### **5.1.1. Integration Management**

For the purpose of operational use of BIM it is very important to effectively plan and successfully execute its processes. In the first hand, successful BIM integration can be achieved by understanding the project needs including employer requirements and project specific conditions. It is also very important to keep in mind that transformation of mindsets to a digital working environment by educating and

motivating people and organisations to make them involve in innovative processes more easily. Successful integration of BIM will potentially benefit the supply chain and create a business value. The first step is to establish the organisational integration for an overall project integration, which includes forming an effective BIM team, enabling the collaboration between parties under the BIM platform and keeping the support and guidance continuous to create an organisational culture for digital transformation.

Technical infrastructure is to be provided by procuring the best softwares, considering the software effectiveness, overall interoperability, project requirements, necessary file types and softwares being used by other parties. Sufficient hardware and equipment procurement is also important for handling coordination in virtual environment, rendering, analysis, simulations in 3D, smart site tracking, laser scanning and so on.

Process planning starts from the contractual issues which may include BIM Protocols and directs the parties by defining obligations of BIM use which is very crucial for BIM integration in a project. Creating a contentful BIM execution plan concerning every party in the project is also very crucial for successful BIM implementation. It may be created separately for the facility management phase of the project. In order to manage key project processes, effective and efficient workflows including roles and processes to get the best outcomes shall be defined with relevant project teams.

### **5.1.2. Project Execution**

Successfully delivering a project depends on effective project execution. According to the strategic planning and integrating key parties into the project, it is time to carefully and effectively execute and bring value in the construction supply chain. The first deliverable of the successful BIM implementation is to develop a fully coordinated and engineered BIM model. Development of the BIM model may depend on the

construction schedule, project needs and employer requirements. Therefore a solid and understandable BIM modelling guideline is needed to set the specifications of modelling for every party to rely on. The BIM model must be finalized including all design decisions and delivered to site on-time to related people in order for site installations to be accurate. It is important to decide on which asset information is needed by the building operators for operational use to develop the BIM model.

In terms of design coordination BIM brings a collaborative workspace for all parties. Together with digital collaborative environment it is possible to connect all parties across the world and let them focus on the work itself. Design workshops using BIM models are an efficient tool for taking fast and effective design decisions. Those decisions can be applied and distributed to the related parties with cloud based collaboration tools such as BIM360. The shop drawings derived from the BIM models can be digitally reviewed for quality checking and validating the compliance with the BIM model.

Finalized BIM models can be used for design document deliverables such as shop drawings and detail drawings. Effective delivery of the finalized and approved design documents including 2D drawings and 3D models to construction site is possible with cloud based construction management tools and mobile tablets. On construction site, it is easy for site engineers to reach final design documents to track site installations for QA/QC and project control and commissioning.

### **5.1.3. Handover and Facility Management Integration**

Before the handover of BIM model to the facility owners, it is important to do the audit of the model. Validation according to the pre-defined specifications needs to be done for model metadata accuracy. COBie is an effective method to deliver operational information gathered throughout the construction.

An integrated dashboard can be established by linking various databases together including BIM, IWMS, CAFM, CMMS, BAS, BMS, ERP and GIS databases. This integration is open to many opportunities such as enabling user journeys, increase efficiency in energy consumption and more efficient maintenance processes.

BIM model when delivered to facility owners, need to be maintained throughout the lifecycle of the building. There may be various operations that requires an update in the BIM model such as changes of design, additional installations, part replacements,

equipment replacements. These changes need to be tracked and integrated into the BIM model accordingly.

#### **5.1.4. Operational Process Management**

Main idea of BIM usage in facility management is to increase the business value. In order to achieve that, there are many areas which BIM integration and establishing a Digital Twin is beneficial. Various processes including Asset Management, Energy Management, Workspace Management, Maintenance Management, Inventory Management, Procurement Management and 3<sup>rd</sup> party integration including tenant management may be integrated to digital twin of the building and managed through an integrated dashboard. Enhanced control, reporting and analysis is possible for those processes with the facility management integration with digital twins.

There is also many opportunities and potential uses such as creating simulations for operational uses and training, automation of aviation processes with BIM and GIS for airports, machine learning and artificial intelligence developments.

## **CHAPTER 6**

### **CONCLUSION**

In this study, to obtain the implementation and benefits of Building Information Modelling in Complex Construction Projects which is İstanbul Airport Project were examined. The summarizes of this report conclusions will enable the other Construction Projects how BIM based Project management can be achieved and how it is executed for all phases from design to operation.

The motivation of implementing BIM involves to direct designing advantages that lead to expanded efficiency for the engineering process and most relevant benefits being the increased participation and team work with different disciplines. Besides, clash detection & resolution, sustainability & energy analysis, planning, QA/QC and facility management are the most common uses of BIM in the Project. Better services and solutions are provided by BIM based Project management. Most significant outcomes are better visualization with all parts and accessibility from everywhere with Field&Glue apps.

Literature states that there are numerous profits associated with using BIM. Better communication with other parties along the supply chain is being reported, and BIM is proving a useful tool in fabricating and scheduling construction.

Database is coordinated and managed in all other parts, shared, preserved and reused by BIM implementation. Through the application of information technology to the problem of describing a building in software, they enable higher quality work, speed, and cost efficiency for the design, construction, and operation of buildings.

There is fast increase in the interest for adopting BIM within the industry's professionals. According to NBS, 2013 statistics results shows that, the level of BIM awareness has increased from 57% in 2010 to 84% in 2012 and the level of BIM usage from 13% to 39% in the same period. BIM will be the main method in which buildings are constructed and operated.

The BIM adoption process has already accelerated in Turkey as the İstanbul Airport project has become a key learning hub not only for Turkish construction industry but also global landmark for digital construction and related project delivery.

Given the fact that 85 percent of a building's life-cycle costs arise after completion of construction (Arayici et al., 2012; Jordani, 2010; Lewis et al., 2010), In the construction planning process, facilities managers are hardly interested, thereby rendering the maintenance policy focused on the "as built" state until construction is delivered.

Sharing details relating to the development of a comprehensive facilities management strategy, creating meaningful key performance indicators, measuring the return on investment, and developing the contract language and documentation will become increasingly necessary for airports to facilitate the complete implementation of BIM (Building Information Modelling for Airports 2016 ).

The research objectives were set as the following:

- To develop an understanding of advantages of BIM usage for facility management
- To provide a guidance of BIM implementation into the building lifecycle effectively and efficiently
- To examine the benefits of enabling BIM during the construction phase of a complex project for the information handover from construction to operation phases

These objectives were achieved in this thesis. The first objective is met by defining the advantages of BIM usage for facility management through a wide range of literature review and showcasing industry practices.

The second objective is met by showcasing a comprehensive case study to explain BIM implementation steps and constructing a framework for successful BIM implementation especially for FM use.

Third objective is met by the explanation of project delivery form design to the facility management including handover of project information to create an accurate BIM model for FM use, including the BIM graphical and non-graphical data validation together with its benefits throughout the project.

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