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T.C.

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A SMART GUIDE FOR BIM ENABLED CONSTRUCTION PROJECT MANAGEMENT AND DELIVERY: ISTANBUL AIRPORT CASE STUDY

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BY

AHMET EKREM ÇELİKEL

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A SMART GUIDE FOR BIM ENABLED CONSTRUCTION PROJECT MANAGEMENT AND DELIVERY: ISTANBUL AIRPORT CASE STUDY

Hasan Kalyoncu University

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By

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ABSTRACT

A SMART GUIDE FOR BIM ENABLED CONSTRUCTION PROJECT MANAGEMENT AND DELIVERY: ISTANBUL AIRPORT CASE STUDY

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M.Sc. in Civil Engineering

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BIM is increasingly adopted by the construction industry worldwide which is an innovative methodology to design, construct and manage a project in a beneficial perspective. As in the international sector, besides, it is ever-increasingly adopted in construction projects in Turkish construction industry. Despite the significance of BIM and digital processes in the construction sector is seemingly to be understood, there are problems in execution in terms of project management and the core BIM and digital processes for construction project delivery.

In this study, BIM based project delivery methodologies are examined in order for reveal a best practice and set a light to the construction sector with an extensive literature review, impacts of BIM implementation into a large scale project is screened right from the inside of the world's largest airport construction project, researched and presented within this thesis in a case study.

Findings of this study shows that BIM is all-important for the construction industry economically, socially and environmentally. Thus, successful BIM execution leads to time and cost savings as well as providing high quality project delivery without minimum waste.

This study generates a smart guidance to a successful implementation of BIM processes from design to operations project delivery and is expected to serve as an enlightening resource for individuals related to AEC and FM industries with gaining a clear and positively transformed perspective on project delivery and management.

Key Words: construction, management, BIM, Istanbul Airport, digital twin

ÖZET

BIM TABANLI İNŞAAT PROJE YÖNETİMİ VE TESLİMİ İÇİN AKILLI BİR REHBER: İSTANBUL HAVALİMANI VAKA ÇALIŞMASI

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BIM, planlama, tasarım ve mühendislik, inşaat ve tesis yönetimi dahil olmak üzere bir inşaat projesinin ve bir binanın tüm yaşam döngüsü aşamalarını yönetmenin bir metodolojisidir. BIM aynı zamanda tüm proje bilgilerinin toplandığı, verimli bir şekilde işlendiği ve çok boyutlu sanal ortamda ilgili taraflara dağıtıldığı, mobilitenin ve yeni nesil dijital servislerle uyumun sağlandığı ortak bir platform oluşturmaktadır.

Endüstri uygulamaları ve akademik çalışmalar BIM'in bir binanın planlama, tasarım, mühendislik, inşaat ve işletme süreçlerinde zaman ve maliyet verimliliği ve kalite açısından proje teslimatını iyileştirmede çok önemli bir role sahip olduğunu açıkça göstermektedir.

Bu çalışmada, örnek bir uygulama ortaya koymak ve kapsamlı bir literatür incelemesi ile inşaat sektörüne ışık tutmak için BIM uygulamasının büyük ölçekli bir projeye etkileri doğrudan projeye dahil olarak incelenmiştir. Dünyanın en büyük havalimanlarından birisi olan İstanbul Havalimanı projesi, bu tez kapsamında araştırılmış ve bir vaka çalışması ile sunulmuştur.

Bu çalışmanın başarılı uygulamaların incelenmesi ve kapsamlı bir literatür taraması sonucunda kompleks inşaat projelerinde başarılı BIM entegrasyonuna yönelik bir rehber oluşturarak mimarlık, mühendislik, inşaat ve tesis yönetimi sektörleriyle ilgili kişiler için aydınlatıcı bir kaynak olarak hizmet etmesi beklenmektedir.

Anahtar Kelimeler: inşaat yönetimi, BIM, İstanbul Havalimanı, dijital ikiz

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Istanbul,
2020

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LIST OF ACRONYMNS / ABBREVIATIONS

AEC Arhitecture, Engineering and Construction

AHU Air Handling Unit

ATC Air Traffic Control

BIM Building Information Management

BHS Baggage Handling System

CAD Computer Aided Design

COBie Construction Operations Building Information Exchange

FM Facility Management

GBS Green Building Studio

HVAC Heating Ventilating and Air Conditioning

IFC Industry Foundation Class

IFC Issued For Construction

IT Information Technology

LOD Level of Development/Detail

MAF Material Approval Form

MEP Mechanical, Electrical and Plumbing

MS Method of Statement

NFI Notification for Inspection

QA/QC Quality Assurance/Quality Control

RFI Request for Information

SAS Special Airport Systems

SD Shop Drawing

1. INTRODUCTION

As the construction industry grows in a fast pace, better project delivery in key aspects such as on time delivery, cost effectiveness and quality of work is needed. The project teams who are involved in a construction project often struggle with false decisions, lack of clean information and reaching them, redo of work and absence of a platform to communicate with each other that affects the success of the entire project with accomplishing the key aspects mentioned above. Furthermore, delivering the project information for the operational phase of the building is another struggle that requires correct data collection and usage of project data during operations.

As a methodology of effective project delivery, Building Information Modeling can provide the entire project an environment where project teams are involved and project information is coordinated in clear, accessible and innovative forms in response to market demand.

In both academic and industrial fields, there has been a huge development in building information methodology, the way it is implemented and tools supporting it. The real revolution in methodology was actually prepared in the academic field since the 70’s (Eastman, 1976) and materialized with commercial software at the end of the 80's. BIM is strongly supported by software tools that allow its adoption. Starting with the very first software presented on the market, many developments have come and brought to users a rich set of functions that allowed the design activity improvement in several ways: quality, reliability in communications, optimized scheduling, error reduction, document management and cost reduction (Luciani, 2012).

In this research, overview of a collaborative approach with BIM and benefits of utilizing it in a construction project are derived. Additionally, a case study of the world's largest airport’s BIM implementation process within an organized framework.

1.1. Background of the Research

As the digital revolution in the construction industry has already begun at different rates, large-scale advances affect the way projects are handled by taking advantage of emerging technology and collaborative methods. Building information modeling (BIM), which is increasingly recognized for its ability to increase project efficiency, is a significant vector for this transformation. (Whyte and Hartmann, 2017). However, BIM has not only the potential to enhance project efficiency as a collaborative solution, but also the consistency and usability of the knowledge needed to move the built assets to operations and maintenance. (Matthews et al., 2018). Although the BIM concept has been widely applied, it is difficult to explain the overall and realistic BIM effectiveness at this point. (Lu, Li, 2011). As in other sectors, it is difficult to achieve high standards of efficiency. In the construction industry, outcomes are dependent on many internal and external factors. BIM can only work with effective and efficient outcomes and add business value if it is applied and implemented correctly and only as necessary.

1.2. Research Questions

BIM provides a platform for visualization, collaboration, automation, integration and communication between the various parties in the AEC industry (Bosch-Sijtsema et al. 2017; He et al. 2017; Zhang et al. 2018). BIM is used over the entire life cycle of construction in conjunction with other interactive resources and links data and knowledge from the design process to the construction phase and finally to the building's management , operation, restoration and demolition. (Bosch-Sijtsema & Gluch, 2019). As a new technology in the construction industry, while BIM is expected to bring many benefits to the industry, its widespread implementation has been hindered by a number of barriers which will be discussed in the following sections (Liu et al., 2015). Hence, in order to provide solutions to those barriers, the research problems of this thesis are formed as following;

How BIM can be used as a construction project management approach to effectively execute project delivery from design to operations to achieve productive project outcomes?

What are the positive impacts of BIM based construction project delivery and full implementation of the methodology in a large scale construction project?

What are the objectives to overcome success barriers for BIM implementation into a large scale construction project?

What should be the BIM implementation strategy and affecting factors of BIM implementation in the project lifecycle?

1.3. Research Aim and Objectives

The main objective of this thesis is to gain understanding about the BIM implementation methodology and execution of it on a large-scale construction project. An overview of BIM will be given as an information management method for efficient project delivery from design to facility management process including a case study of Istanbul Airport in order to maintain empirical data for the purpose of the research. This study also aims to contribute to the development of the construction industry by increasing the understanding on project management and delivery by implementation of BIM by increasing the understanding about the impact of organizational structure.

Objectives are designated to fulfill the answers of the research questions and finding solutions to reach the barriers in front of the BIM implementation in large scale projects.

Objectives of this thesis are as following;

- To emphasize and activate the important role of BIM, and the potentials of eliminating the barriers in front of BIM implementation in the large scale projects with strategies by technological and organisational aspects.
- To examine uses and purposes of BIM and its role towards a more efficient and effective management of project phases of buildings
- To verify that BIM has positive effects on successful project delivery if it is efficiently implemented into a construction project lifecycle
- To investigate how BIM is successfully implemented into the project lifecycle of Istanbul Airport with a case study
- To establish a BIM implementation guidance by addressing challenges and success factors towards successful BIM implementation in large scale projects

1.4. The Research Approach

A deductive and qualitative analysis methodology is the research approach followed in this study. The researcher will analyze the case study of Istanbul Airport and the collection of data from a qualitative analysis approach.

1.5. Organisation of the Thesis

This study is organized under the following sections; Introduction (Chapter 1), Overview for Concept of Building Information Modeling (Chapter 2), Research Methodology (Chapter 3), Case Study (Chapter 4), Discussion and Findings (Chapter 5) and Conclusion (Chapter 6).

In Chapter 1, the introduction including background of the research is given briefly. Also the purpose of the study and the research problems are determined. Finally, the research approach is defined.

In Chapter 2, concept of BIM was explained and an overview of BIM implementation was done with a wide range literature scan. In this chapter, fundamentals of BIM is briefly addressed. Definitions of key terms and workflows of the overall process are given.

In Chapter 3, research methodology for this thesis is explained in a detailed manner.

In Chapter 4, a case study of Istanbul Airport is included where BIM is fully implemented with providing empirical project data. For the construction project delivery with BIM implementation, an overall review of the methods applied in order for project success is briefly explained with provided real-time data for the study.

In Chapter 5, with the collected data from the case study, the impacts of successful BIM implementation to a large scale construction project are defined and results are discussed.

In Chapter 6, conclusion of the study is given based on the findings and a summary of the results. Findings of the study is achieved in terms of the challenges faced throughout the implementation process and positive impacts on project success derived from the case study.

1.6. Scope of the Research

The scope of this thesis is the investigation of successful BIM implementation by deducting information from a case study and develop a guide for successful BIM implementation.
This study answers the issue of how the deployment of BIM is feasible in large and complex construction projects.

1.7. Ethical Consideration

According to Denscombe (2005), The ethics or values of general science apply to conformity with the interests of study participants. In the whole report, the researcher has a responsibility to respect secrecy, dignity, informed consent and anonymity.
For the collection of data for the production of this study, an ethical approval form was sent to Istanbul Airport for this study.

2. OVERVIEW FOR CONCEPT OF BUILDING INFORMATION MODELING

In this chapter, general information on Building Information Modeling together with its international development, adaptation strategies, implementation methodologies into engineering projects are explained in the light of a wide range of resources from standards to academical studies.

2.1. What Is BIM? – Purpose of the concept

Building information modeling, abbreviated BIM, is a methodology that brings everyone and every useful data a new dimension in a condition of effective collaboration in order that the construction project or a building be delivered under control with a fast, cost effective and high quality mechanism. BIM is not only a tool to create a 3D model of a building. It can be considered as a project delivery method or a management perspective which is very strong in various manners.

In literature, there are multifarious definitions of BIM, which has been very popular in the last decades in both academic and industrial terms and increasingly implemented in the construction industry in the last several years. In one of the definitions BIM is defined as a method for integrating knowledge and technology to produce a digital representation of a project that incorporates data from multiple sources and progresses in parallel with the actual project over the entire timeline, including planning, development, and in-use operational information (Mordue et al., 2016). In another article it is stated that BIM is a mechanism based on the creation, use and conversion of a building project's digital knowledge model to facilitate the planning, installation and function of a project or facility portfolio (Messner, et al. 2011).

2.1.1. International Development of BIM

In international construction industry, BIM is very well developed in terms of standardisation. Plans, procedures, publicly open standards and frameworks were produced in a structured manner in various developed countries. In this chapter, a brief information about the standardisation processes of BIM in United States and United Kingdom and the standards that has been developed in those countries are explained.

In the United States; The National BIM Standard– United States® (NBIMS-US™) Version 3 (V3), developed by the building SMART alliance ® National Institute of Building Sciences, which includes key consensus-approved guidelines for the sharing of knowledge and best practices for the application of BIM on a project and it is published in order to give a structure for BIM implementation industry-wise. Addition to that standart, there are multiple open information standards has been developed and being used across the country.

In United Kingdom; a range of publicly available specifications (PAS) were produced in order to provide specific guidance for the information management requirements associated with projects delivered with BIM. In one of the specifications, It is mentioned in PAS 1192-2:2013 that it is important to understand its potential use for the development of data to be genuinely lean. This is done by starting with the end in mind" and defining the downstream applications of data to guarantee the data can be used and reused during the asset's project and life. It is for this reason that PAS 1192-2 was made. In order to fullfil strategic objectives such as reducing the cost of public sector assets by up to 20% by 2016, there has been a variaty of documents published under BIM Task Group which is a UK government initative.

By at least 2016, the UK government would need entirely collaborative 3D BIM (with all project and asset data, reports and data being electronic). This applies to all centrally procured government projects, including new development and retained land, vertical and linear, as illustrated in the GCS (UK Government Construction Strategy, 2011). With this regulation, public sector construction projects are forced to use BIM in the project delivery process in order to reduce additional capital delivery costs amounting to 20-25%. (The British Standards Institution, 2013). In another terms, Level 2 BIM (described below) is mandatory for all public construction projects.

The UK government has accepted that the process of bringing the construction industry to 'complete' collaborative work would be incremental, identifying various and identifiable benchmarks in the form of 'levels' within that process. These have been described within a range from 0 to 3, and although there is some discussion about of level's exact meaning.

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 Group. The 2008 Bew-Richards Wedge defines the evolution of the integrated and interoperable Building Information Model from conventional CAD. Its aim was to clarify BIM maturity, to give people a sense of their BIM maturity, and to provide a strategic roadmap for the growth of BIM implementation. THE 'BIM maturity' is referred to as transition from one stage to another. The BIM levels are listed below and visualised in Figure 1. (Barnes and Davies, 2014):

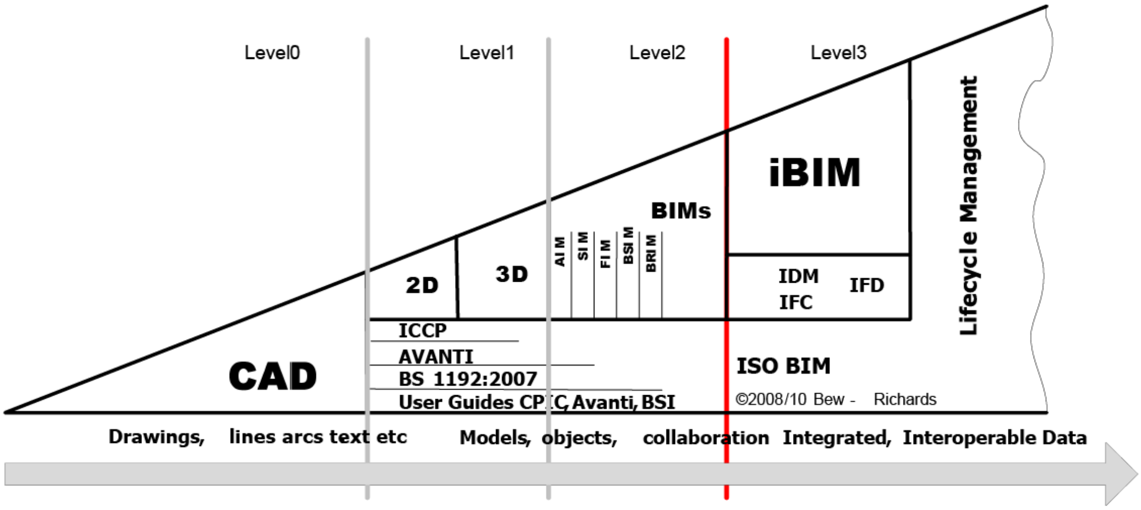


Figure 1: Bew-Richards BIM Maturity Levels

- Level 0 isn't really BIM at all. It relates to use of 2D CAD files for design and production information. (Hellum, 2015)
- Level 1 represents the first step toward genuine BIM and the use of 3D data to present design. Designers at this level usually use managed CAD in 2D or 3D format with collaborative tool providing a common data environment, where standards for data structures and formats are utilized. Finance and cost management packages are not integrated in the general BIM model. (Hellum, 2015)
- Level 2 BIM can be seen devided from Level 1 especially because of the collaborative working envorinment. In order to create a combined BIM model and to carry out interrogative tests on it, template data is shared through a standard file format, allowing any individual to merge the data with its own. All parties have their own 3D CAD templates, but they do not always run on a single universal platform. Collaboration can be established in terms of information sharing between various parties and is the primary function of this stage. Therefore any CAD program used by each party must be capable of exporting to one of the standard file formats, such as IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange). This is the working approach set as a baseline goal by the UK government for all public sector jobs by 2016. (Source: National Building Specification for the UK online article, 2014)
- Level 3 would be a real-time project paradigm that is fully embedded and collaborative and is likely to be supported by online services. This BIM stage will use 4D building sequencing, 5D cost information, 6D project life-cycle information and other dimension

management information, and will be powered by the creation of common object data libraries that will provide information from suppliers (Hellum, 2015).

In a research in Turkish construction industry, Level- 2 BIM is implemented at a rate of 49% as observed which is the most common one. Level-1 implementation s a rate of 30% and Level-3 has a rate of 21%. (Özorhon and Karahan, 2016).

There are international standards on BIM including BS EN ISO 19650-1: Concepts and principles and BS EN ISO 19650-2: Delivery phase of assets which both were published on December 2018. BS 1192 (principles) and PAS 1192 part 2 (capital/delivery phase) will be superseded by these two standards.

An internationalization of the UK's BIM Level 2 with the same principles is the ISO 19650 standard. It is therefore expected that it will fit very well with the existing requirements of PAS 1192-2. This implies that organizations would need to begin upgrading from their existing PAS 1192-2 certification to the latest ISO on the introduction of ISO 19650. (British Standards Institute, 2018)

2.2. BIM as a Project Delivery Method: Design to Operation Delivery

From the design phase of a construction project to facility management, BIM acts as a delivery method which provides an effective collaboration based on a 3D model, lean information flow and support for project teams in order to deliver the project in many aspects in terms of collaboration.

2.2.1. BIM Execution and Implementation Strategy

Having a clear plan and strategy is essential to the success or failure of BIM implementation.There is a need for overall strategy for encouraging BIM in between the project teams both in the office and on site. (Mordue et al., 2016). BIM protocols and frameworks are generated in various institutes that can be used internationally to refine and improve processes and quality assurance (Explained in Chapter 2.1), and develop individual BIM execution plans for particular projects. (Mordue et al., 2016). In Figure below, there is the Information Delivery Cycle that is a part of PAS 1192-2:2013.

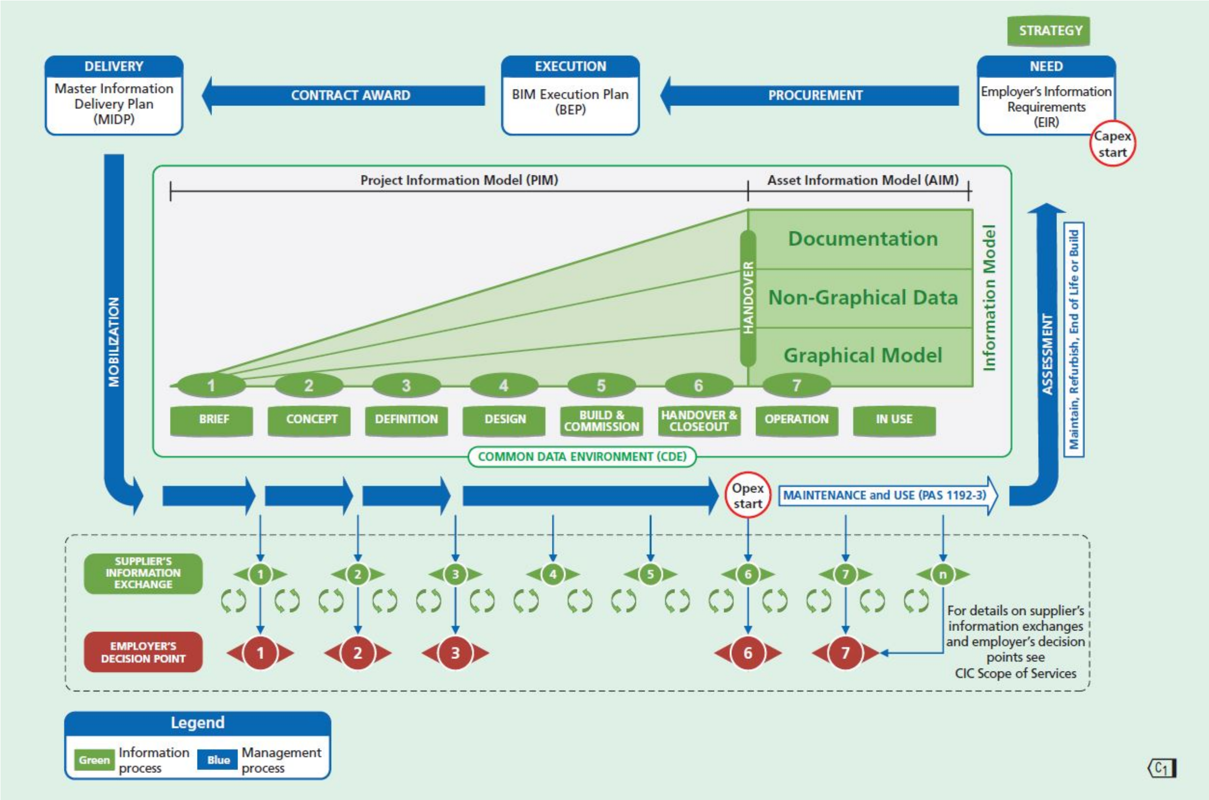
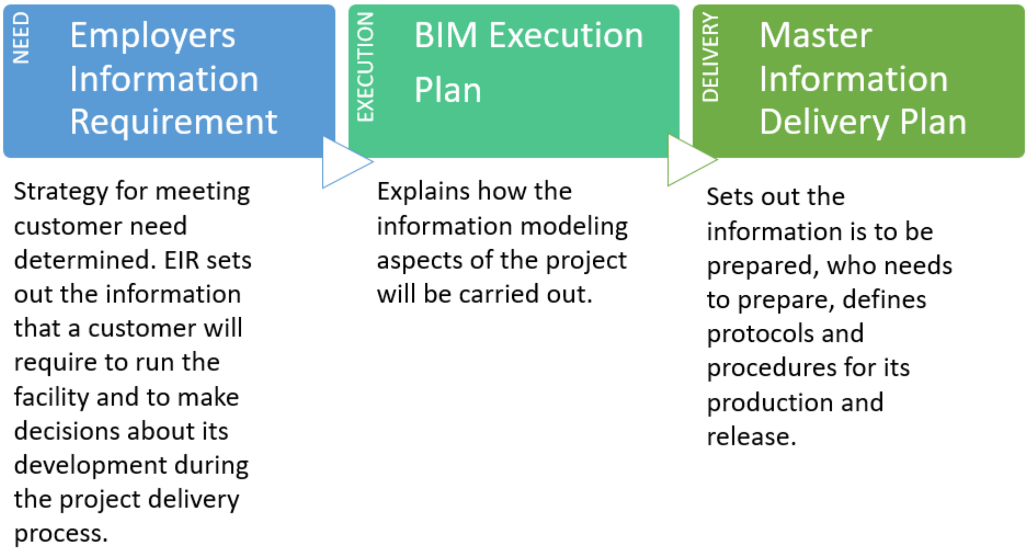


Figure 2: Information Delivery Cycle (PAS 1192-2:2013)

There are two different entry points in the information transmission cycle, as seen in Figure 2. For stand-alone new construction projects, start with the "Need" box at the top right, but for projects that are part of a broader portfolio or land, or for projects that operate on existing buildings and structures, start with the "Assessment" right-hand arrow, which draws on the details in the current Target. In the CDE, these entry points are also referenced. It is expected that portfolio data will be used to guide decisions at all starting points. In green, the information delivery cycle illustrates the



generic process of defining a project need (which may be for design services, construction or supply of goods), procurement and award of a contract, mobilization of suppliers and generation of production and asset information that is important to the need. For every aspect of a project, including the refining of design details through the seven project phases shown in green color, this cycle is followed. In Orange, the numbered ovals and annotated lozenges correspond to the CIC Continuum of Services stages. The GREEN picture reflects the CDE that will gather, preserve, disseminate, exchange and retrieve information throughout the lifecycle. Small GREEN balloons suggest knowledge exchanges with members of the project team. In order to answer the Plain Language questions asked by the employer, information exchanges among the project teams and the employer are shown by larger red balloons defined in the employer's information requirements (EIR). (The PAS 1192-2:2013 Notes for Figure 3 are derived)

Figure 3: Information Delivery Cycle (PAS 1192-2:2013 cycle explanation is derived from theb1m.com)

2.2.1.1. BIM Execution Plan

BIM Execution Plan (BEP), which can also be used as BIM Project Execution Plan (PxP) is the core document for implementing BIM. As a result of the project team's decision, this paper explains how BIM can be adapted to the project. Each project have a specific BIM Execution plan that can be arranged for specific needs for the project.

Guides Messner et al. (2011), VA BIM Guide (2010), AEC (UK) BIM Technology Protocol (2015) and Singapore BIM Guide (2013) state that comprehensive and thorough preparation must be carried out by the project team in order to implement BIM. At an early stage of a project, BEP should be performed. The plan should include options, duties and documentation of the process. (Pellinen, 2016).

As the primary means of project coordination, the Project BIM Team should not rely on information exchange; information exchange is not collaboration. Using the model as a common resource, the Project BIM Team should arrange daily BIM planning meetings during which team members meet to address design and construction issues. The frequency of such interactions depends on the aims of the project, BIM uses, and the capacities of members of the Project BIM Team. The Project BIM Team should negotiate through the BIM project planning process on how and in what ways the members of the Project BIM Team would collaborate using the BIM. A project-specific BIM PxP should be developed and approved by all project stakeholders concerned with modeling. This plan should include the criteria for the sharing of knowledge between the participants, as well as for planned interactions with the model. The

BEP should clearly describe all of the above information. (National Institute of Building Sciences, 2017)

The file sharing requirements should also be defined clearly in BEP. Based on the project's BIM uses, those criteria may differ. The PxP can at a minimum, contain a definition of the following;

- File system(s) which will be used by the project team in order to share, integrate and visualize the models.
- Schedule for or pace of model changes and controls for clash detection.
- Resources and approaches to be used for confirming clash identification .
- Method to be used to create drawings from coordinated models (National Institute of Building Sciences, 2017).

2.2.1.2. Information Models

In the basis of the BIM approach, there is a multi-dimensional model concept which includes graphical and non-graphical data together with linked databases which may also include non graphical and documented data. This data will need to be stored in a data storage, which can be established in local data centers or in cloud environments. This base model can be described as a Project Information Model (PIM) according to the BIM Task Group.

An Asset Information Model (AIM) is a model that includes all the digital data necessary for the asset to function and fulfill the described purpose. AIM is based on the final, checked, "as-built" data and can be used facilitate a digital environment for operations and maintenance processes of a building. This digital archive includes the history and components of the building and the details required in the future for decision support. Processes such as maintenance operations planning, failure root cause identification, service life planning, etc. need to be facilitated.

The actual model or database should be a single user information system, but several separate databases, file stores and bi-directional links to business systems and domain resources can be included underneath the model. The Goal includes asset design and development data, augmented by ongoing operational, maintenance and minor and substantial adjustments over the life cycle of the asset. The data is a mixture of geometry which commonly is 3D models, structured data (equipment history records, sensor data etc.) and documents (o&m manuals, contracts, warrants, lists of spare parts etc.). (Areo Blog, 2016)

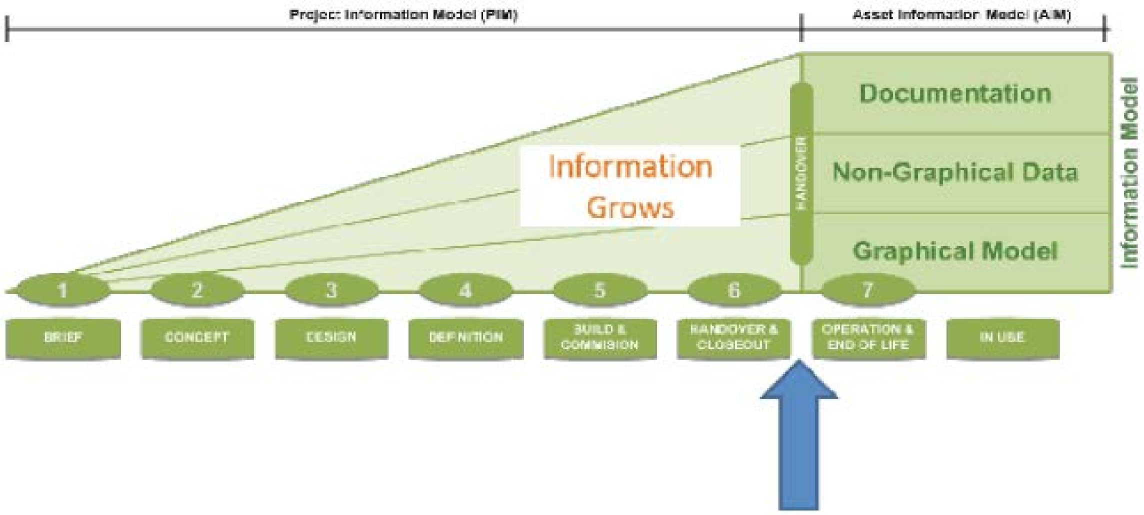


Figure 4: Project Information Model and Asset Information Model

Before embarking on the road of building the digital asset knowledge model, an organization will build and publish a business case. They will need to identify the benefits they want to gain; time and cost it will take to create a data and file store; to allocate the information that will be needed to define; to gather that information; what kind of people and how many people will be needed to conduct the job and provide governance; to extract information from the asset information model and produce reports and what kind of software tools will be used. The identification of the possible benefits of building a digital knowledge model would be one of the first steps. Any of the advantages may be as follows:

- Reduced costs due to the automated transition from construction to operation of information.
- Less manual data entry.
- More detailed knowledge to reduce the cost of management.
- Thanks to the availability of better knowledge about the asset, less issues and costs during the early operation of a new or refurbished asset.
- The potential to reduce costs for service and maintenance.
- More emphasis on long-term operational efficiency makes better informed operational expenditure and capital expenditure decisions.
- Reduced remedial costs due to less building errors during early service.

- Savings from life-cycle decisions, guided by a single integrated, up-to-date data source.
- Better resilience modeling and failure risk.
- Enhanced spending decisions to promote knowledge processing for asset management. A source of dynamic metering and condition sensor data records to detect poor output of electricity, faults and the risk of imminent failure.
- The business owns and retains all its asset data for potential procurement (Manning, BIM Task Group, 2014).

2.2.1.3. Collaboration Among Project Parties and Common Data Environment

Azouz et. al, cited in an article that it is difficult to find effective means of communicating and organizing activities to facilitate cooperation in the AEC sector that are seen as necessary for the realization of projects (Hensel, Menges and Weinstock, 2006; Kocaturk, 2013). The problem lies in the repetitive cycle of data distribution; it consists of many cycles of development, storage, manipulation and revision. Indeed, knowledge in a project network is typically poorly organized, scattered and distributed. In fact, one drawback of conventional information management is the inaccessibility of information within a temporary project network. (Fischer and Kunz, 2004). As a result, for the past three decades, research efforts in the field of information technology in the AEC industry have been at the forefront of attempts to identify, formalize and incorporate construction information. (e.g. Björk, 1992Many people see BIM as the result of these efforts. (Crotty, 2011). Among its many marketed advantages, BIM is seen as the product of conventional paper-based information exchanges to reduce the loss of information assets over the life cycle of a facility. (Eastman et al., 2011). In other words, through its centralization, BIM helps users to be more involved in their knowledge exchanges. BIM 's creation was planned to eradicate the chaotic flow of information by proposing the model shown in Figure 5. (Dubler et al., 2010). In light of this, the management of information is becoming a central theme related to the emergence of BIM (Froese, 2006). Therefore, problems related to how data is obtained, shared, visualized and recovered are at the heart of many research efforts (Nepal et al., 2012; Redmond et al., 2012; Singh, Gu and Wang, 2011; Wu and Hsieh, 2012).

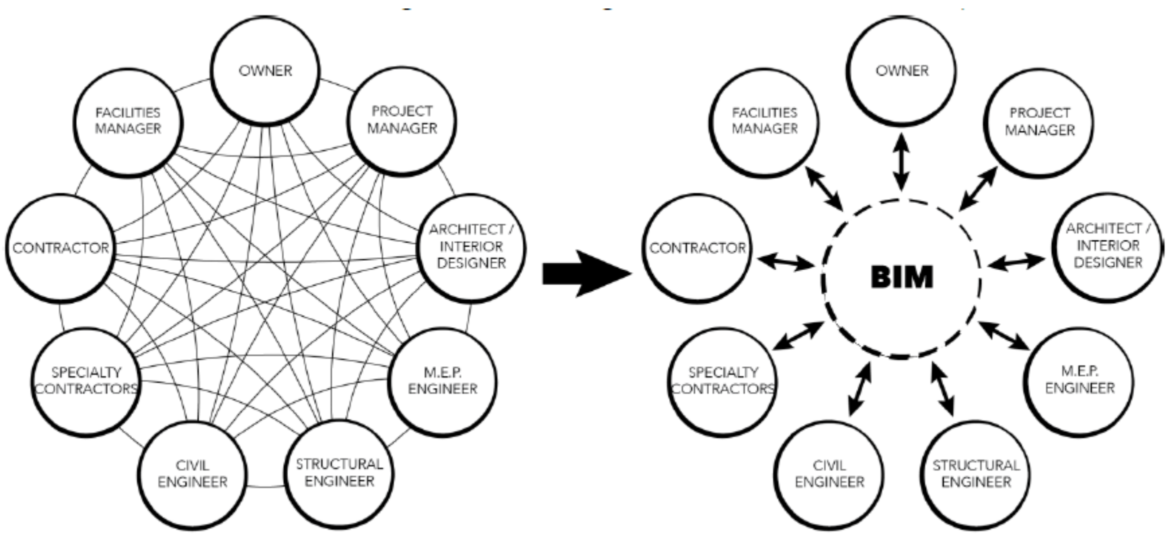


Figure 5: Centralizing Information (adapted from Turk, 2001)(source: Azouz et. al, 2014)

In “UKBIM2: A Short Guide” John Eynon states that, Over the entire lifecycle, BIM is just about developing, preserving and using knowledge and data, seamlessly and successfully by all stakeholders. This involves, briefly, concept, design, procurement , manufacturing, building, commissioning, handover, service , maintenance, refurbishment, and eventual recycling. The term used in the PAS 1192 series, the Common Data Environment, is probably the more correct way of looking at this - all data accessible to everyone over the lifecycle in a common environment. Organized, consistent, coherent, transferable, efficient.The output of digital information sourced from common data environment are further explained in dimensions of BIM, Chapter 2.5.1. in this thesis study.

2.3. BIM Implementation Barriers

In the construction industry, Several difficulties that can be classified into five major categories have limited BIM implementation: lack of a national standard; high application costs; lack of trained personnel; organizational problems; and legal concerns. As seen in Table 1, each barrier can then be divided to two or three subgroups (Liu et al., 2015).

Table 1: Barriers in BIM implementation summary table (Liu et al., 2015)

Category	Item	Literature
Lack of International Standard	Incomplete national standad	Bernstein & Pittman, 2004; Thomson & Miner, 2006; Björk & Laakso, 2010; Azhar, 2011; Aibinu & Venkatesh, 2014; Alreshidi et al., 2014
	Lack of information sharing in BIM	
High cost of application	High initial cost of software	Allen Consulting Group, 2010; Thomson & Miner, 2010; Azhar, 2011; Ganah & John, 2014
	High cost of implementation process	
Lack of skilled personnel	Lack of professionals	Smith & Tardif, 2009; Allen Consulting Group, 2010; Sharag-Eldin & Nawari, 2010; Becerik-Gerber et al., 2011; NATSPEC, 2013 ; Wu & Issa, 2014
	High cost of training and education	
Organisational issues	Process problems	Arayici et al., 2011; Won et al., 2013; Aibinu & Venkatesh, 2014; Demian & Walters, 2014
	Learning curve	
	Lack of senior support	
Legal Issues	Ownership	Thomson & Miner, 2006; Chynoweth et al., 2007; Azhar, 2011; Udom, 2012
	Responsibility for inaccuracies	
	Licencing problems	

The creation of a national BIM implementation plan will set out national goals and provide guidance across the industry as a whole. The BIM method needs to be standardized and guidelines for its implementation must be released (Azhar, 2011; Thomson & Miner, 2006). There is, in addition, a need for well-developed practical methods that identify the styles of work in the sector (Bernstein & Pittman, 2004). There is no clear general consensus about the application and use of BIM, however.

Some guidelines have been established for construction, to coordinate industry practice, however, there is no uniform norm. Standards are popular in the AEC industry (Björk and Laakso, 2010), but new standards need to be established to incorporate BIM. The absence of a The national standard for sharing data in the implementation process between all stakeholders is seen as an obstacle (Allen Consulting Company, 2010).

While the AEC industry is expected to benefit greatly from BIM, its implementation requires costs, as with any new technology. The perceived costs of implementing BIM technologies are curriculum and preparation costs, management and start-up costs, and adjustment and behavioural costs. The implementation costs are often recognized as an obstacle to the implementation of BIM. The rise in BIM implementation in the industry is predominantly within large resource-driven businesses (Ganah & John, 2014).

The obstacles to BIM implementation mentioned above influence each other. Figure 6 demonstrates the ties between the implementation of BIM and the five barrier groups. Implementation of BIM is not only a technological challenge and has an impact on the organizational structure and work processes of different organizations in the AEC sector. Organizational challenges emerge from this form of transition. When the implementation of BIM is connected to external parties outside the company, such as suppliers, it will include economic and legal issues. Implementation of BIM reduces the costs of building projects significantly from the outset (Allen Consulting Company, 2010).

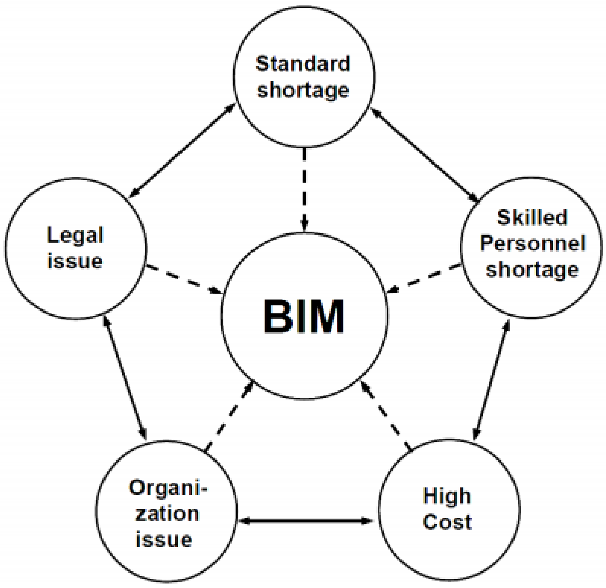


Figure 6: Relationship between main barriers (Liu et al., 2015)

2.4. Change Management

BIM users report that at an earlier stage in the project, design effort increases but decreases later on. In 2004, when he compared historical workflow and integrated project delivery workflow, Patrick MacLeamy, CEO of HOK which is a firm that is using BIM actively, predicted this trend. As the cost of making design improvements increases with time, there is an improvement in the opportunity to enhance design and reduce costs. In a diagram that is now known as the MacLeamy curve, the four variables are graphed (Figure 7). If this definition is right, integrated work will save money by bringing the design change to an earlier, less expensive stage of the project (whatever contractual form it takes).

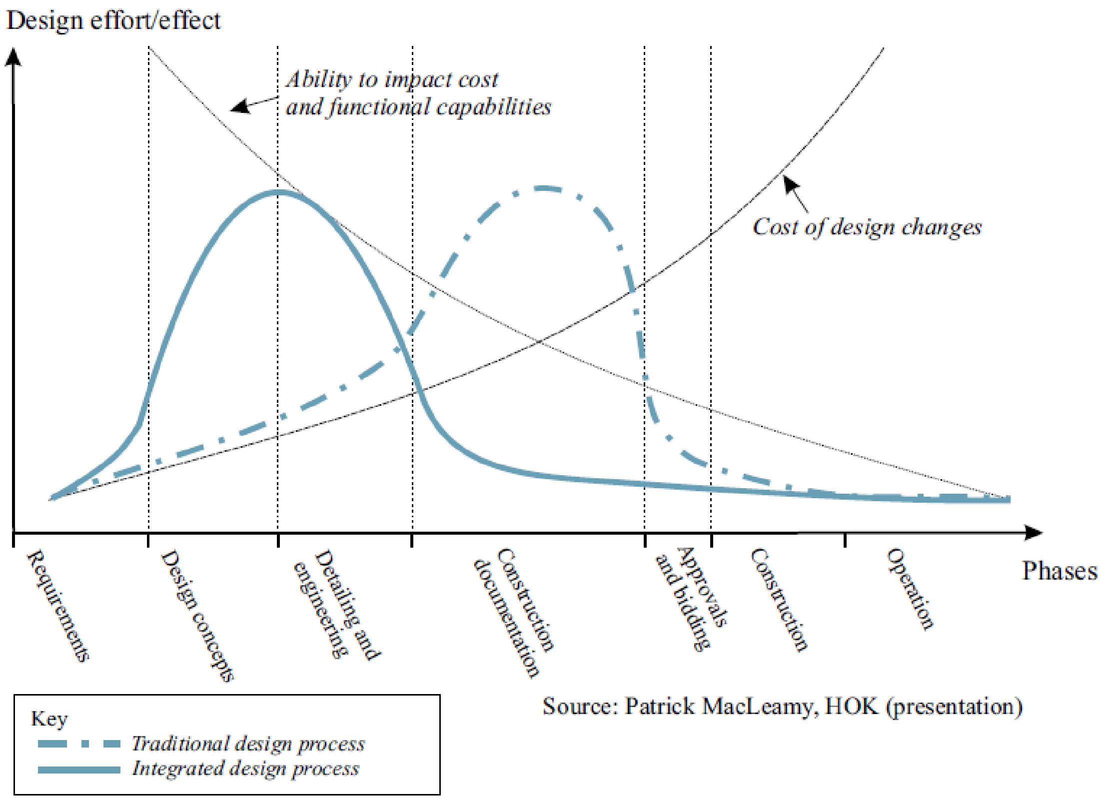


Figure 7: Mac Leamy Curve (source: Patrick MacLeamy)

Involving all people in the implementation process of BIM is one of the key factors in order to successfully adapt BIM processes. Despite BIM is not a new term to the construction sector, there is still much to do to deal with the challenge of a cultural change in order to shift people into a new mindset.

Effective leadership is one of the most important critical success factors on BIM implementation according to Ozorhon and Karahan (2016). Commitment and leadership by senior management for creative training systems is necessary for the effective execution of BIM and the expertise of company workers (Arayici and Coates 2012).

To build capability across the organisation, training may also be required. From learning the principles and using the program right down to document management, both disciplines may require training in BIM techniques. A broad practice to create BIM Super Users in offices (British Standards Institution, 2010). Effective leadership and training need are human related factors. The other critical success factors represented and discussed by Özorhon and Karahan (2016) are listed in Table 2;

Table 2: Critical Success Factors for BIM Change Management

CRITICAL SUCCESS FACTORS	
Human	Experience level within the firm
Industry	Awareness level of the industry
	Appropriate legislation
	Knowledge sharing
	Governmental schemes
Project	Coordination among project parties
	Client requirement
	Project size
Policy	BIM policy of the company
	Supportive organizational culture
	Consulting
Resources	Availability of qualified staff
	Availability of information and technology
	Aavailability of financial resources

2.5. BIM Production Processes and Outputs

In this chapter, general information on BIM production and outputs are covered. Commonly known BIM dimensions, Level of Development stages of BIM Model and technical aspects of utilizing BIM are briefly explained.

2.5.1. Dimensions of BIM

In this chapter, dimensions of BIM including 2D & 3D graphical data, 4D (Planning), 5D (Quantity Take off and Cost Estimation), 6D (Facility Management) and beyond 6D are defined briefly. Table 3 shows the relation between dimensions of BIM and stakeholder impact.

Table 3: Dimensions of BIM (Pärn et al., 2016)

Dimensions of BIM.

Dimension of development	Descriptions	Stakeholder impact
3D	Consists of two and three dimensional model data to represent the building design. 3D BIM can also be defined as: "*geometric presentation, parametric descriptions and legal regulations associated with the construction of a building*" [70].	Design team, supplier
4D (3D + time)	Links scheduling/time related information to the 3D model's objects in order to sequence the construction process over time [65].	Contractor, sub-contractor
5D (3D + cost)	Adds cost related information to the 3D model's elements. This enables early cost estimation and quantity take offs directly from a single 3D file (ibid.).	Quantity surveyor
6D (3D + FM)	Integrates FM and building lifecycle information. 6D is related to asset information useful for facility management processes, but after 5D no general consensus on the dimensions has been reached in the literature (ibid.).	Facility manager, building owner
nD (3D + ...nD)	Other possible dimensions associated with the BIM model.	Can relate to any specified stakeholder.

2D & 3D - 2D refers to two-dimensional drawings, for example, plans, sections, elevations. 3D adds "height." Often when referring to a BIM, one is referring to this 3D digital model.

4D – The fourth dimension is simply the time, implemented to the 3D model as schedule data. This can be done element by element or asset by asset, depends on the project needs. At the end of the implementation, there is a simulation of 3D models with a timeline, enables project teams to see the project at a high level perspective. Zhao notes that it would help builders to fix building sequence conflicts with this visualized timeline before the project starts and locate missing tasks. In certain ways, 4D scheduling and 5D estimating have saved building firms a large amount of time and expense because the visualized management will avoid future schedule problems from being avoided by contractors.

5D - Throughout the entire design and development process, the use of cost estimation tools within BIM is critical. Part schedules, such as doors and windows, are relatively simple to make, as are the measurements for material volumes and surfaces. Particularly in the early phases of programming, by using quantity take-offs, the owner can get forecasts from a basic BIM for the estimated cost of the project. If more data are added on real geometry, components, and finishes, more detailed calculations can be made. (Kensek, 2014)

6D – BIM for facility management is the next dimension. During Operation & Maintenance, More than 80% of the time spent on an FMT is spent seeking important details that designers frequently neglect during pre-construction work (Becerik et al., 2011). For the purpose of asset management, such data is critical when handing over an accurate as-built model to building owners. The Institution of Civil Engineers notes that these challenges can be eliminated by the availability of a secure, BIM based knowledge set. (Pärn et al., 2016)

nD – In the literature and practical use, other dimensions of BIM Model exist such as safety measures, environmental analysis etc.

2.5.2. Level of Development

Document E202 of the US American Institute of Architects (AIA) sets the standard of production for model components. Think about the level of creation as the criterion for both the graphical level of the geometry of the object, called the level of detail (LOD), and the non-graphical details in the object, called the level of information (LOI). In combination, these two levels form the stage of growth.

LOD100: Symbols in the model may imply a component's presence. The height, shape, or exact position is not shown by the symbol. Any component of LOD100 must be treated as estimated data. A geometric presentation of a structure is not LOD100.
LOD200: Model components are planned as widespread structures or assemblies
The quantity, scale, structure, position and orientation are approximate. Model Elements can also have nongeometric details attached. A generic placeholder is shown by LOD200. The part or system it serves may be defined. They can also be only room booking or volumes. The details is estimated for each piece of LOD 200.
LOD300: Model Components are based on the quantity, scale, form, position and direction of real assemblies. Model Components can also have non-geometric details attached. All of these above can be calculated from the model without additional information.
LOD350: Besides LOD300 there are also the requisite for coordination between various system objects. These modules also can provide supports for systems and detailed connection models.
LOD400: Model Elements are modeled as unique assemblies which with complete manufacturing, assembly, and details details, have consistency in their scale, shape, position, number or orientation. Model Elements may also provide non-geometric detail. The precision of LOD400 meets the particular element's manufacturing specifications.

LOD500: Model Elements are based on the present and correct scale, structure, position, number and orientation of built components. This is also commonly known as as-built model. Model elements can also provide nongeometric details. (Hellum, 2015)

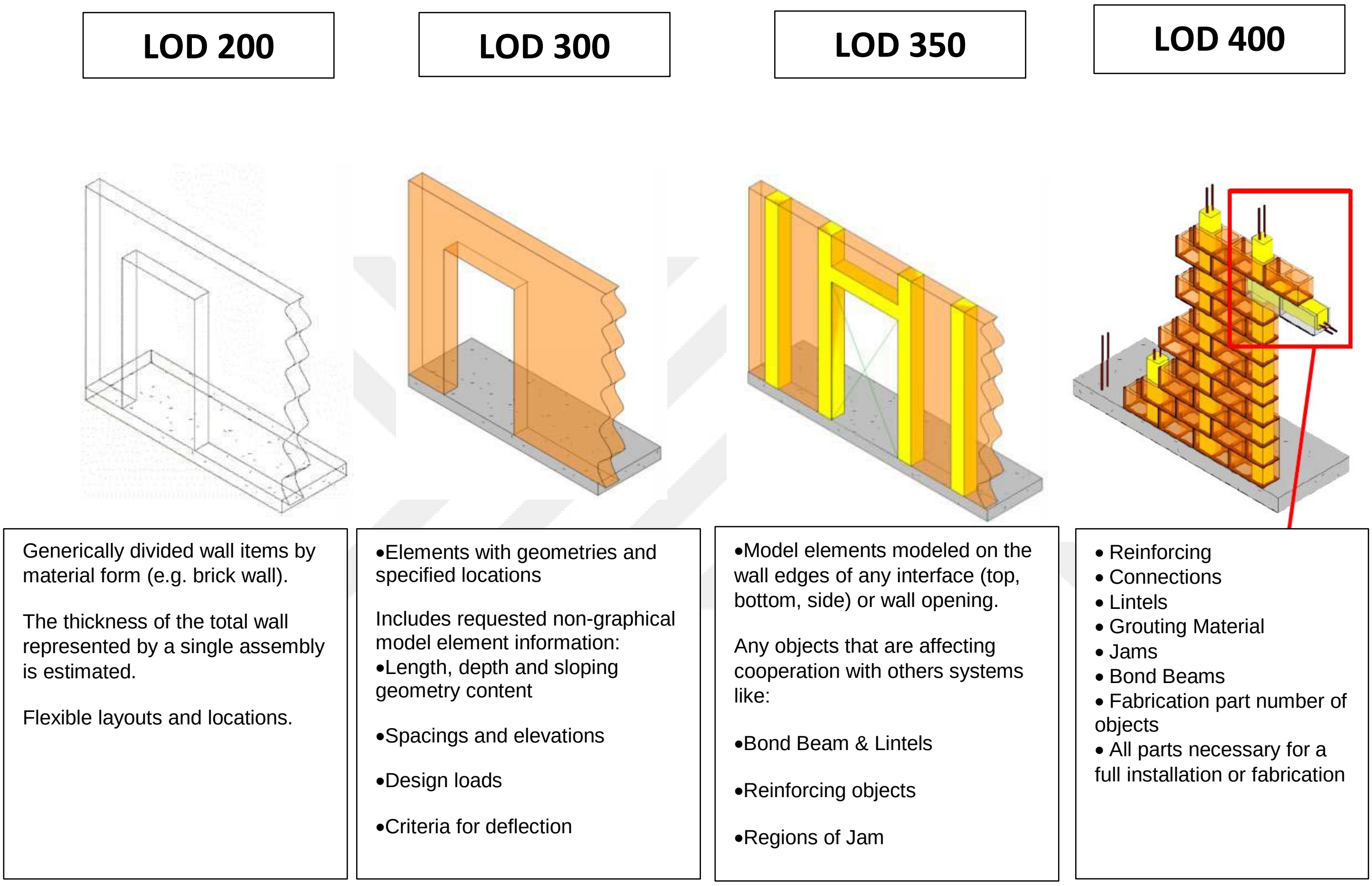


Figure 8: Level of Development of a Masonry Wall (Images from LOD Specification, 2015)

LOD is often viewed as Information Level rather than Production Level. There are major distinctions. How much detail is used in the model part is basically the degree of detail. Development level is the grade of which the geometric and non geometric information of the element has been considered. The degree to which members of the project team can depend on the details while using the model. In essence, it is possible to consider the level of detail as an input to the feature, whereas the level of production is a reliable output. (Level of Development Specification, 2015)

These best practices to be used in the model development process are described in the AEC (UK) BIM technology protocol: it is important for the smooth exchange of information that specific guidelines for internal and external collaborative work be established that protect the integrity of electronic data. This is equally relevant for the decision points of the employer, the sharing of knowledge from manufacturers and the iterative model sharing of design data between these more formal deliveries. (Pellinen, 2016)

- Identify consistent ownership over the life of the project of model components.
- To prevent file sizes being too large or sluggish to work within the accepted project volume plan, sub-divide models between disciplines and within single disciplines.
- Understand what is to be modelled and to what level of detail (LOD) and clearly record it. Avoid over-modeling.
- Clearly describe the data (Level of Information (LOI)) to be integrated in the stage-relevant BIM.
- Together, at every stage in the design and development process, the LOD and LOI help to better express the requirements of the BIM content and clarify the level of description. Level of Definition = LOD + LOI
- Avoid disconnecting 2D views or production from the primary 3D model. In order to maintain the credibility of the model and synchronization between the BIM and its performance, changes to the project should be made "at source" (i.e. in the model) instead of changing the 2D.
- Outstanding alerts are periodically reviewed and critical issues are addressed.
- Traditional drawing conventions also apply where drawings are a product of the BIM. (Pellinen, 2016)

2.5.3. Technical Aspects

BIM has certain specific features that can be used in project management effectively. These increasingly evolved features can be summarized as follows: (Lahdou & Zetterman, 2011):

- **Clash Detection:** The inconsistencies in geometric design are one of the common issues in the designs of various disciplines for a construction project. This problem arises when there is an overlap between various disciplines' plans. It would be possible to put the plans together using BIM and detect the clashes. Another option of this visual checking is to adjust the esthetic issues. (Rokooei, 2015)

- **Constructability**: It is possible for teams in a project to review and resolve problems related to construction using BIM and encourage problems in RFIs. In addition, to illustrate the issues, visual information may be given from a vantage point. This corresponding visual information markup allows for further investigation to find alternatives and thereby mitigates the risks. (Rokooei, 2015)
- **Analysis**: BIM also allows project teams including managers, designers, engineers and consultants to do further research and to allow better decision making. The energy use of a construction project could be measured by connecting building information models to appropriate resources, and then finding better solutions, such as material and orientation changes, weight, and space. In addition, BIM includes illumination, mechanical and acoustic studies. (Rokooei, 2015)

2.5.4. Information Exchange

A crucial element for success in project management is the fair use and understanding of terminology. (Project Manager Education and Opinion, 2012). For this reason, during the last decade, some efforts have been made, such as building SMART, formerly the International Alliance for Interoperability (IAI), an international organization with the goal of improving informative contact between different applications of construction software. As a neutral specification for building knowledge models, BuildingSMART has built Industry Foundation Classes (IFCs) (Words & Images, 2009). The Industry Foundation Classes were created to provide a wide range of compatible building information data representations for the sharing of various software in the construction industry. (Figure 9).

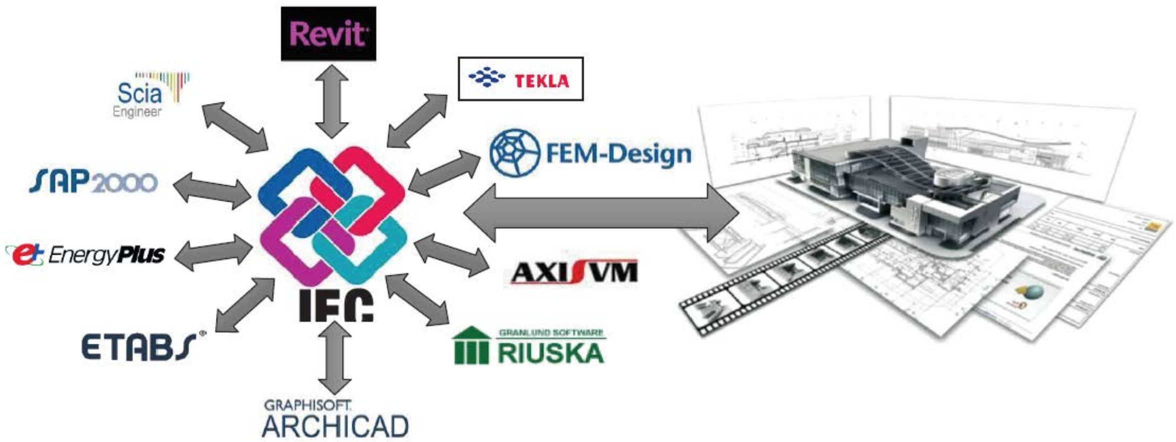


Figure 9: Mutual relationship between IFC and Some BIM applications (Rokooei, 2015)

This is a systematic approach that recognizes all aspects of the life cycle of a construction project. Data interoperability is a crucial factor in obtaining BIM productivity as an item of the buildingSMART alliance. Therefore, it seeks to establish a common data schema that facilitates the exchange of data between different BIM applications. This data scheme contains interdisciplinary building details, from feasibility to operation and maintenance, as used in the project phases. (Rokooei, 2015)

Wasted effort is mainly caused by duplicated work in a complicated supply chain, where other suppliers have to re-enter or replicate data used further down the supply chain, mainly because the software used by each party is not interoperable. A few years ago in the US, the National Institute of Standards and Technology (NIST) looked at this issue and calculated the overall cost of insufficient interoperability at $15.8 billion per year, equal to 2.84% of the annual value of construction (British Standards Institution, 2010). Interoperability is the ability of BIM software to send and receive data through the use of widely accepted data specifications such as gbXML and IFCC from other BIM software. (Gelder et al., 2013).

3. RESEARCH METHODOLOGY

3.1. Introduction

This part of the thesis consists of the topics about how this research was conducted. Information on the research process, philosophy, approach, strategy and data collection methods are explained.

3.2. Understanding the Research Process

According to Saunders, Lewis and Thornhill (2007), Research onion gives a comprehensive overview of the approach used in research. Research onion concept is represented in Figure 10.

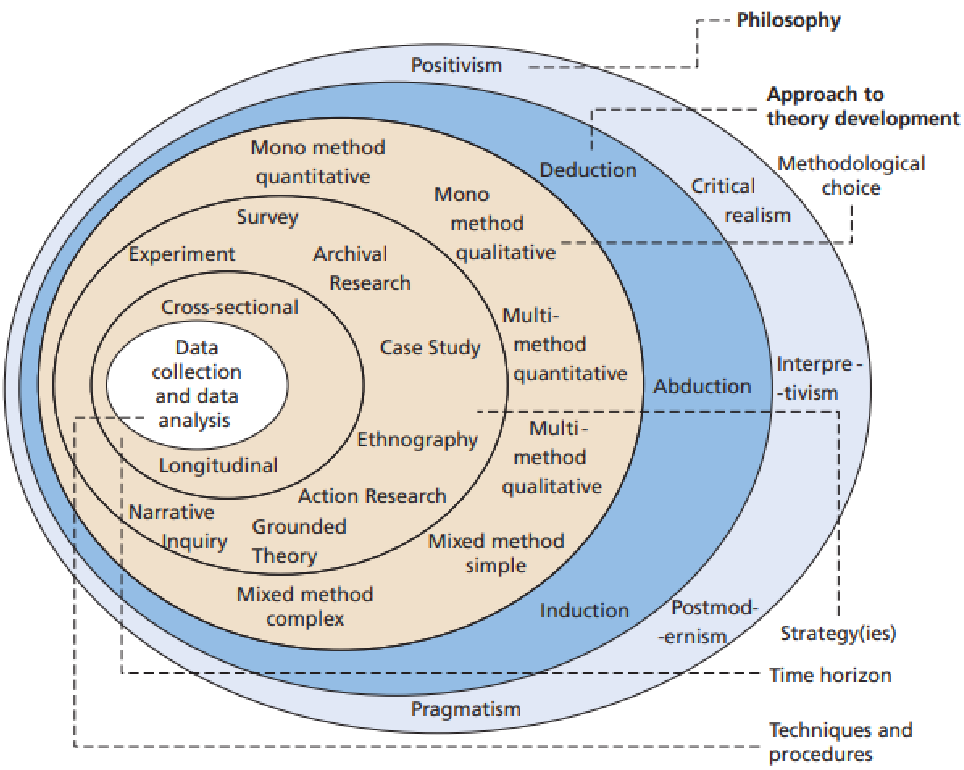


Figure 10: Research Onion Concept, Saunders et al. (2006)

The research onion contains seven layers, separated into research philosophy, action research strategy, research strategies, time horizon, and analysis methods and data collection (Saunders , Lewis and Thornhill, 2007). The researcher will access the required information on the layer of the given onion concept while doing this study.

3.2.1. Research Philosophy

The philosophy of research refers to a concept or conviction in the compilation, presentation and analysis of data. The philosophy of research discusses the origins, existence and creation of knowledge (Bajpai, N., 2011). Saunder 's research onion concept, which includes Positivism, Realism, Interpretivism, Pragmatism as the most important concepts relevant to research, is clarified in Saunder 's research onion concept. (Saunders, Lewis, and Thornhill, 2007). To keep it reasonably straightforward, Saunders, Lewis & Thornhill, states three types of science principles that differentiate research philosophies: ontology , epistemology, and axiology.

Ontology refers to assumptions about the nature of reality. Ontological expectations form the way the research objects are perceived and analyzed. Organizations, administrators, daily lives of people and corporate activities and artifacts are part of the company and administration of these objects. In order to understand the market and the management world, Ontology describes the choice of the research project (Saunders, Lewis, & Thornhill, 2012).

Epistemology refers to knowledge assumptions, what constitutes reasonable, true and true knowledge and how information should be conveyed to others. (Burrell and Morgan 2016). While ontology can at first be very abstract, epistemological significance is more evident. With the multidisciplinary context of business and administration different kinds of information can be considered valid, including numerical, textual and visual data, details, views and stories. Therefore the different researchers from companies and management use various epistemologies including archival and autobiographical studies (Martí and Fernández 2013), narratives (Gabriel et al. 2013) and fiction literature. (De Cock and Land 2006).
Axiology revers the position of values and ethics. The researchers want to see the influence of their own principles and convictions on study as a good thing as a basic axiological preference.

Our research concepts start by considering the ontological position which deals with the fundamental nature of life and for which there is no correct or incorrect response, since different people interpret concepts differently according to their role, values or context.

3.2.2. Research Approach

A literature review has been done where a wide range of articles, thesis, journals and books were scanned online. This review was done to give the study a structured context. Additional to that, a case study was done in order to show implementation of BIM in a large scale project.

There is also an active research methodology where the writer is deeply involved in the industry with the research problem in mind providing real time data. Gill and Johnson (1991) use ideas of Kolb et al (1979) to explain the theoretical basis of research as shown in Fıgure 11.

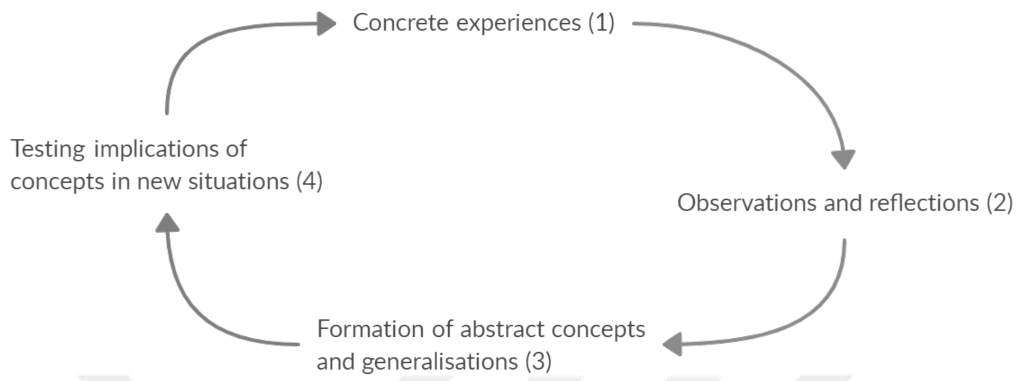


Figure 11: Kolb's experimental learning cycle (Gill & Johnson, 1991)

Gill and Johnson (1991) propose that the processes of Kolb in Figure 11 can be seen as attempts to build and test conceptual claims, or theories, about what is happening around us and argue that these help one to discern between deductive (logical-based) and inductive (empirical-based) analysis approaches.

3.2.2.1. Deductive Approach

Researchers verify the hypothesis and the argument in a deductive analysis approach before proceeding to the outcome, which is more precise, the final part is the inference that relies on available evidence (Jonker and Pennink, 2009).

3.2.2.2. Inductive Approach

The inductive approach to science includes objective study that leads to more generalisation and the development of theory. It is from the particular to the general, as stated by Myers (2009), and this approach is predominantly used in qualitative analysis.

3.2.2.3. Quantitative Approach

Numbers and frequencies are the subject of a quantitative analysis approach. The approach does not stress the definitions and knowledge, but therefore quantifies the captured data subjectivity to rigorous and strict analysis (Kothari, 2008).

3.2.2.4. Qualitative Approach

The evidence gathered in a qualitative analysis explains variables rather than reaching a statistical conclusion. The approach is also part of unstructured exploratory analysis by subjectively analyzing significant factors in character, actions, mood, opinion (Myers, 2009). Qualitative experiments are intended for explanatory purposes, as stated by Kothari (2008) (Kothari, 2008).

To describe qualitative analysis, various authors use various terminology. The word "descriptive research" was used by Clark (1991); "field study" by Schatzman and Strauss (1973); "participant observation" by Jorgensen (1989); "case study" by Yin (1984); "naturalistic research" by Kidder (1981). Wright (1995) determines qualitative study to mean any study where the core problems are not empirical counting and computational tools, where an effort is made to get close to the data collected and their natural context. She provides a number of strategies including participant evaluation and case studies, review of material, formal videotaping, unobtrusive steps, archival data assessments, frame analysis, issue-area analysis, ethnomethodology, and discourse analysis, and casual questioning.

This thesis is a qualitative study with a deductive approach to research. The investigator will analyze the case study, direct observation and collection of data here.

3.2.3. Research Strategy

The research method, which refers to different techniques implemented for a specific analysis, such as trial, survey questionnaire, case study, dependent hypothesis, ethnography and archiving, is the next significant layer in the Saunders research onion. (2007: Saunders, Lewis, & Thornhill). The five research techniques are survey study, ethnographic study, experimental study and case study, according to Fellows and Liu (2008). Yin (1996) states that the methodology applied to any study depends on the form of research issue, including the intended outcome, the degree of control needed, the time emphasis (now or past), objectives and priorities. A detailed overview of the research methods is given in the section below.

3.2.3.1. Experimantal Research Strategy

Experimental research aims to verify the findings and establish the relationship between cause and effect, often in physical sciences. Isolation of variables, replication of tests, and standardized evaluation of effects are the key characteristics of the technique.

3.2.3.3. Exploratory Research Strategy

The aim is to devise a new viewpoint on a problem in exploratory science and explain what is happening (Pope and Mays, 2006).

3.2.3.4. Case Study Research Strategy

Case study definition is made by Yin (1994, p.13) :

A case study is an empirical study that explores a contemporary phenomena in the sense of its real life, particularly if the borders between phenomenon and context are not obvious.

3.2.3.5. Action Research Strategy

According to Coghlan and Brannick (2009), the strategy of action research seeks to identify an urgent solution to a community problem. Via action research, data on existing issues can be evaluated and potential developments expected (Jonker and Pennink, 2009).

3.2.3.6. Grounded Theory Research Strategy

This theory is primarily applicable to qualitative social science studies. The method includes formulating a theory, gathering knowledge, and coding the gathered data. To form a hypothesis, the coded data is then clustered (Charmaz, 2006).

3.2.3.7. Ethnography Research Strategy

This method is applicable to qualitative analysis, whereby the researcher has to engage for a given time with the sample population to gather the necessary data. The research approach for ethnography enables the gathering of first hand data from a given research community or category (Murchinson, 2009).

3.2.3.8. Archival Research Strategy

The research method for archiving is the final stage of the research plan; it is focused on the sample resources, the whole sample will be focused on records kept by several other scholars, therefore there is a vast amount of data in this research technique, therefore data can not be monitored too often, and thus provisional conclusions are not feasible on the basis of such data. (Towl and Crihton, Graham, 2010).

3.2.3.9. Adopted Research Strategy

In this research , the researcher applied the methodology of case study to collect certain data. The approach followed includes a technical and literature analysis on BIM recognition innovations and the supply chain of construction, case studies on BIM delivery activities.

3.2.4. Research Choices

The next layer in the research onion is selection which can be further divided into mono, mixed and multiple methods. The mono method adopts only one method of study, while both qualitative and quantitative methods are used in the mixed technique. Several approaches are used in several strategies (Saunders, Lewis , and Thornhill, 2007) .

Wright (1995) goes on to argue clearly that the resulting analysis would be even more relevant by integrating qualitative techniques with quantitative methods (Figure 12) and would be more likely to be accurate, to really quantify what it purports to measure.

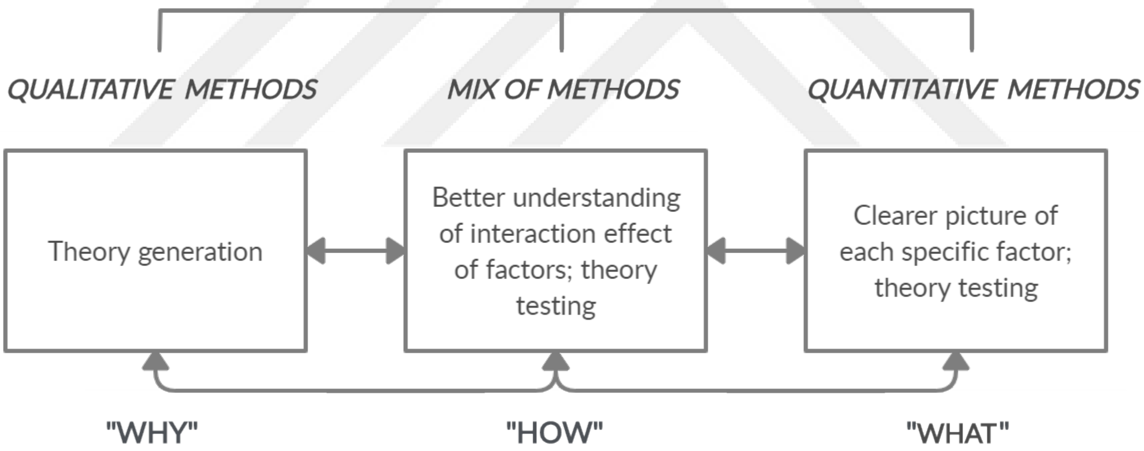


Figure 12: Appropriate use of qualitative and quantitative methods in international management research. (Wright, 1995)

The researcher utilized a multiple approach in this research, not only the qualitative and quantitative methods of research. The approach to analysis is an inductive approach that combines qualitative and quantitative evidence. In order to achieve the conclusions from the case analysis, a number of testing approaches are incorporated.

3.2.5. Time Horizon

The concept of a time horizon is a fixed time goal and a time period under which it is necessary to complete a mission or function. In relation to the conclusion of a study, the first type of time period is longitudinal, which has no fixed time for data collection, interpretation and sample conclusion. A prefixed time is set for the completion of the study for the second form, cross sectional (Saunders, Lewis and Thornhill, 2009). For this research, cross sectional time horizon type is used to collect data in the case study method.

3.2.6. Research Process and Plan

The research design process and methods used for this study can be seen in the Figure 13. The result is determined by the selected methodology and research design. Thus, all methodological assumptions, strategy, research design and methods applicable to the thesis need to be addressed. Figure 13 illustrating the phase-by-phase study processes aimed at establishing BIM implementation guidance for a complex construction project.

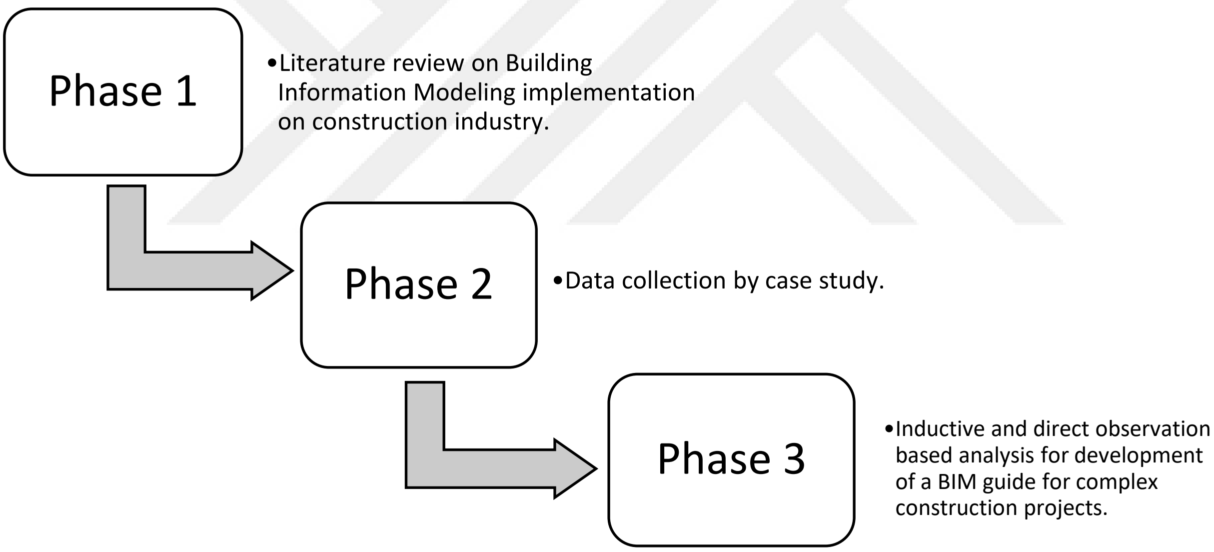


Figure 13: Research design process

3.2.7. Data Collection and Data Analysis

The most significant elements of the research study are data collection and interpretation. The data is routinely collected and the study of the data collected refers to the issue of research by particular methodology and method (Bryman and Bell, 2007). The reliability and legitimacy of analysis are specifically responsible for data calculation (Wood & Ross, 2010). Therefore, the primary data and secondary data for any study are the two forms of data obtained for a comprehensive analysis. In this research, primary data collection of both qualitative and quantitative methods are adopted by direct observation, whereas the researcher was also working in the project as Senior BIM Engineer and participated all executive processes throughout the project.

4. CASE STUDY FOR BIM IMPLEMENTATION IN İSTANBUL AIRPORT CONSTRUCTION: DESIGN TO OPERATIONS DELIVERY

4.1. Istanbul Airport Project Information

The İstanbul Airport (IGA) is distinguished by being the largest investment of infrastructure projects in the history of the Turkish Republic, with an approximate investment cost of €10.25 billion. When it is completed, it will be possible for the airport to be extended into 200 million per year capacity once all its phases are over. The goal is to complete the IGA in four phases which phase 1 is already finished. The airport is situated on the northern area of the European side of İstanbu, on an area of 76.5 million square meters, including İmrahor, Tayakadin, Yeniköy Ağaçlı, Akpınar and İhsaniye villages and is located in a region 35 km from the town centre.

Figure 14: 3D Render of IGA (Courtesy: IGA)

When all phases are completed, IGA is projected to become one of the world’s largest airports with its facilities including 6 independent runways suitable for all types of aircraft, 16 taxi roads, parking capacity for 500 aircraft, 3 different terminal buildings with piers, including railway connections between them. The main terminal building which is planned to be completed in the 1st phase has more than 1.5 million square meters construction area including 5 piers for aircraft docking. VIP lounging, the freight and air terminals, state guest house, outdoor and the indoor parking lot with around 70,000 vehicle capacity, and the air traffic control tower. Total apron area of IGA will be 4.5 millions meters square. IGA will be serving as a hub and transfer center for 350 destinations and 150 airline companies. Master Plan of Istanbul Airport together with construction phase timeline is given in Figure 15.

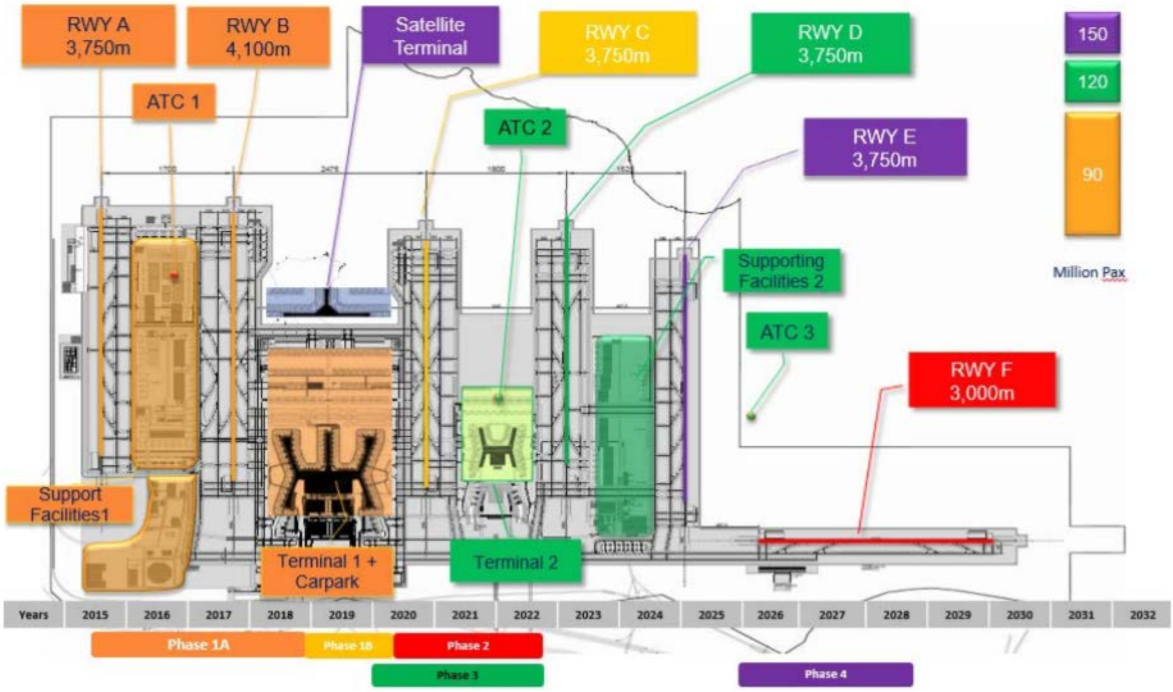


Figure 15: Master Plan and Phases of Istanbul Airport

First phase of the project includes the main terminal and 5 piers, 3 independent parallel runways with 3,75 and 4,1 km length, taxiways, apron, air traffic control tower, closed carpark, fire fighter and emergency buildings, de-icing buildings, hangars, cargo facilities and other facilities. The official completion date of the first phase of construction, which will serve 90 million passengers, is projected to be completed in 3 years. At the end of the first phase, İstanbul Airport will be at 90 million per year capacity. The terminal will have simultaneous passenger bridge service for 114 aircraft.

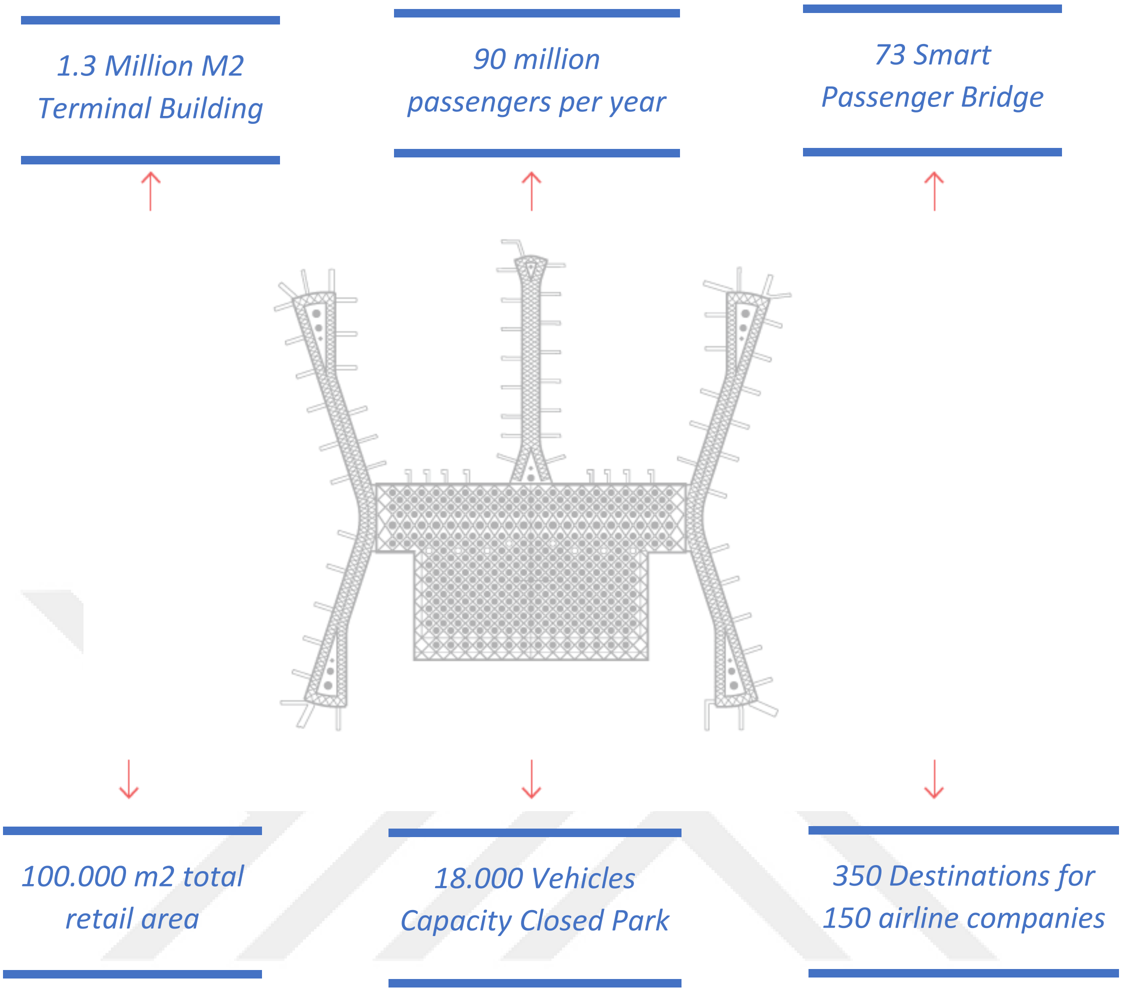


Figure 16: Main Terminal Building of IGA
(Image Source: INA Economic Impact Analysis Report, June 2016)

By providing revenue until 2025, the additional household income to be produced by İstanbul Airport is $3.8 - $4.4 billion and its contribution to the national economy of Turkey is up to 4.2% - 4.9% of the national income. It also will impact 194 to 225 thousand people in terms of income. The Istanbul Airport project was selected among 162 competitors from nearly 30 countries around the world as a finalist in the large infrastructure category of the Autodesk 2016 AEC Excellence Awards.

The main terminal building and piers architectural zones are given in the below plan. PB stands for Pier Building and TB stands for Terminal Building.

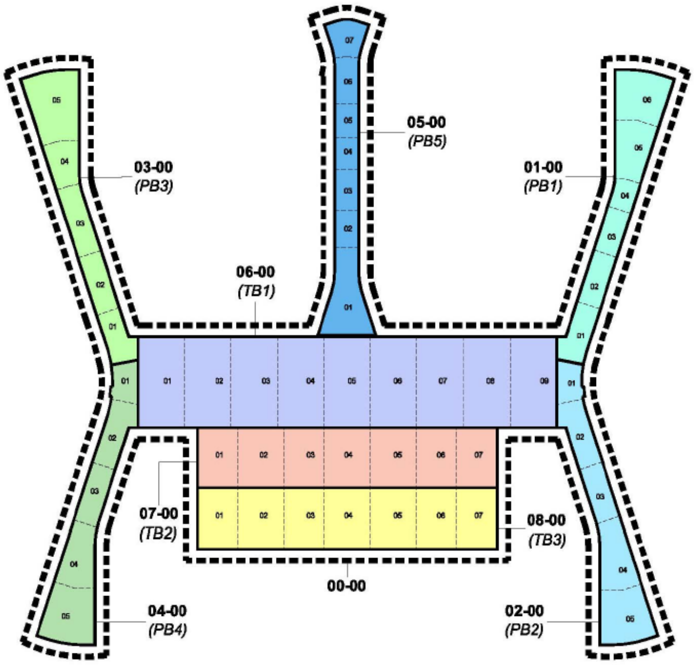


Figure 17: High-level zoning of terminal building and piers

Also the level details of main terminal, piers and carpark are shown in Figure 18 .

TERMINAL BUILDING LEVEL DETAILS

LEVEL CODE	ELEVATION	LEVEL DESCRIPTION
L	+42.00	Roof Level
K	+31.90	Office / Hotel Roof
J	+28.10	Office / Hotel Level 3
H	+24.30	Office / Hotel Level 2
G	+20.50	Retail Mezzanine / Office / Hotel
F	+15.00	Departure Level
E	+ 8.00	Mezzanine Level
Y	+ 3.50	BHS Mezzanine
D	+ 0.00	Arrivals Level
C	- 7.00	Escape Corridors
B	-12.00	Basement Level
A	-20.00	Metro and Train Station

PIERS LEVEL DETAILS

LEVEL CODE	ELEVATION	LEVEL DESCRIPTION
G	+22.00	Roof Level
F	+13.50	Arrival Level
E	+ 6.50	Departure Level
D	+ 0.00	Ramp Accm. & C Gates
C	- 6.00	Escape Corridors
B	-12.00	APML

CARPARK LEVEL DETAILS

LEVEL CODE	ELEVATION	LEVEL DESCRIPTION
Level 6	+15.00	Level 3
Level 5	+10.00	Level 2
Level 4	+ 5.00	Level 1
Level 3	+ 0.00	Ground
Level 2	- 4.20	Basement 1
Level 1	- 8.40	Basement 2
Ground	-12.60	Basement 3

Figure 18: Levels of Terminal & Pier & Carpark Buildings

The asset, zone and level planning given above is the language of the project, also providing consistent strategy for the modelling and coordination process. As the construction and production on site is parallel to the design coordination, strategy for coordination process is very important in order to deliver the coordinated end product to site on time. BIM enables design to site delivery process smoothly with minimum errors and time loss.

4.2. BIM Project Lifecycle Management

BIM is fully implemented from design to construction and facility management at İstanbul Airport. In the case of design and collaboration, BIM in IGA was the connecting platform for all the relevant parties. In the process of design and engineering, a clash-free engineered and constructable BIM model is produced including all disciplines. This model then delivered to construction site with mobile applications periodically. This results in the organized design being applied more efficiently and accurately without any delay and with less on-site issues. BIM is also being used in QA-QC, quantity surveying, planning and project control, energy

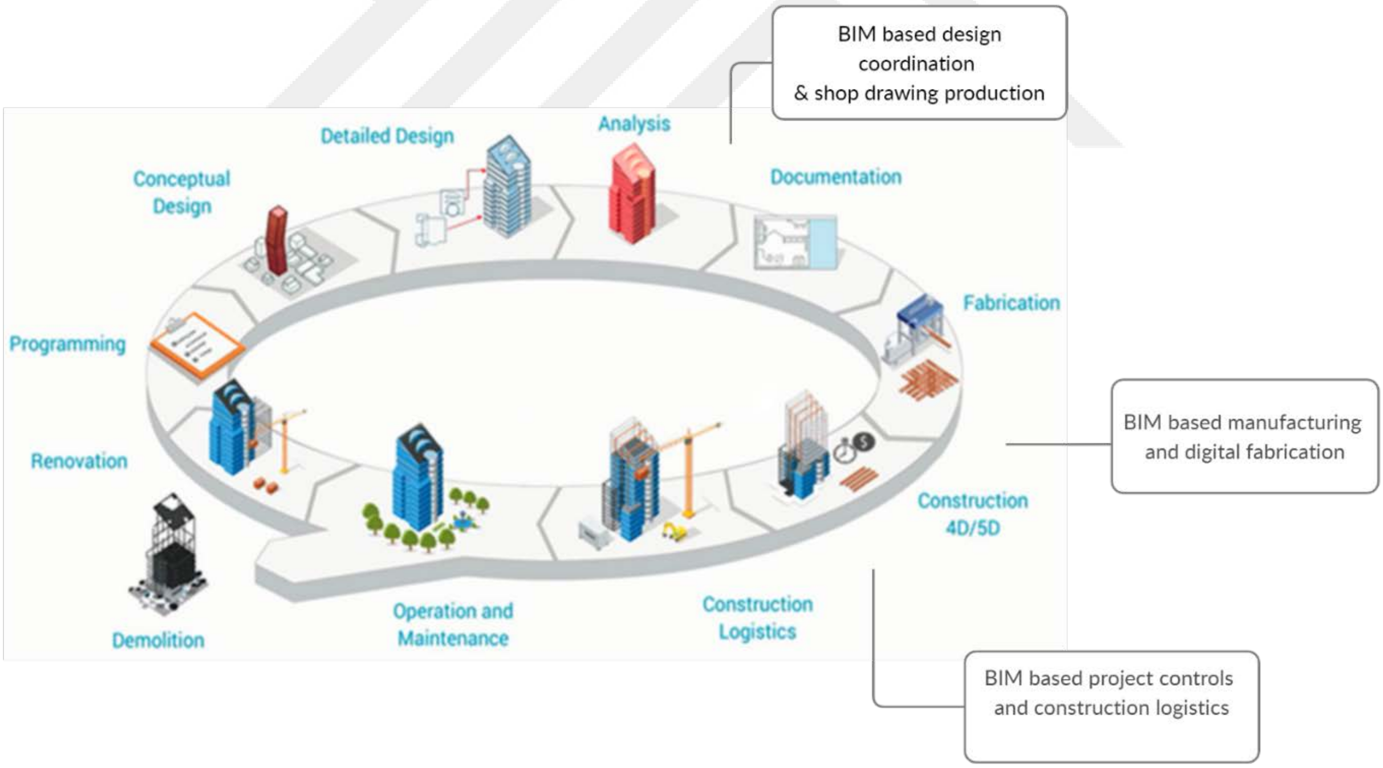


Figure 19: Project Lifecycle and Role of BIM

The process of designing, integrating and documenting the lifecycle of a building by using an intelligent virtual prototype of the building running on an information database in IGA is the core of BIM based Project delivery. Highly automated and integrated environment across all phases including design, construction and operations of the project lifecycle is provided. As a result, required project information will be available to whom ever needs it, whenever it is needed and whenever it is needed. In Figure 19 above, there is the project lifecycle and what BIM provides during the lifecycle is illustrated.

One of the most interesting and outsanding aspect of this application is the way the main points of BIM based project management are reflected. 150 iPads, including all synchronized BIM models used by site engineers. Together with coordinated and ready for construction 3D Models, 2D shop drawings compatible with BIM models are provided within mobile BIM scope. QA/QC processes are digitally implemented into the BIM cloud system accordingly in all disciplines providing progressive and immediate reach to information and collaboration to site engineers with their mobile tablets. BIM360 platform of Autodesk is used as construction cloud collaboration tool. Furthermore, a massive 4D model has been generated by integrating and linking more than 30,000 construction activities into the model to showcase the project progress in a daily, weekly, monthly and yearly basis in a virtual environment to have a dynamic control over the project planning. Executive reporting are done in a weekly basis through the 4D BIM model for executive to take critical decisions on key project tasks.

BIM has a crucial role for design and construction phases of the İstanbul Airport project. However it is not only design and construction processes benefit from BIM, it is also facility management stage of the airport that BIM will be at a key point for better operations infrastructure where there is a 25 years operating period for the contractors. The use of BIM would make it easier to effectively collect all the necessary details and address potential operating issues relating to airport systems during the pre-commissioning, commissioning and maintenance processes. In addition, it is expected to extend BIM to all dimensions so that after the completion of the first phase resulting in the provision of sustainability, 6D of BIM including facility management/lifecycle management process is scheduled to be launched.

4.2.1. BIM Execution Plan and BIM Implementation Strategy

BIM Execution Plan (BEP) was prepared in the beginning of BIM implementation process. BIM execution plan helps collaboration between relevant project individuals and draws a framework that covers the methodology of how BIM is going to be implemented and project to be executed. To execute BIM effectively, a project team must carry out extensive and systematic planning. A well-documented BIM Project Execution Plan helps to ensure that the benefits and obligations associated with the integration of BIM into the workflow of the project are clearly known to all parties. The required uses for BIM on a project (e.g. design authoring, cost accounting, or design coordination) should be identified by a completed BIM Project Execution Plan along with a thorough design and documentation of the process for executing BIM over the life cycle of a project. If the strategy is developed, to achieve the full benefits from BIM execution, the team should follow and track their progress towards this strategy.

Figure 20: BIM Execution Plan Cover of IGA BIM

4.2.1.1. BIM Execution Plan Content

The content of BIM Execution Plan in IGA is based on the BIM Project Execution Planning Guide that offers a standardized process for creating and implementing a BIM Project Execution Plan, which is included in National BIM Standard of United States, Version 3

(NBIMS-US V3). Under the method, the four steps of BIM Execution Planning Procedure and explanations are given in Figure 21.

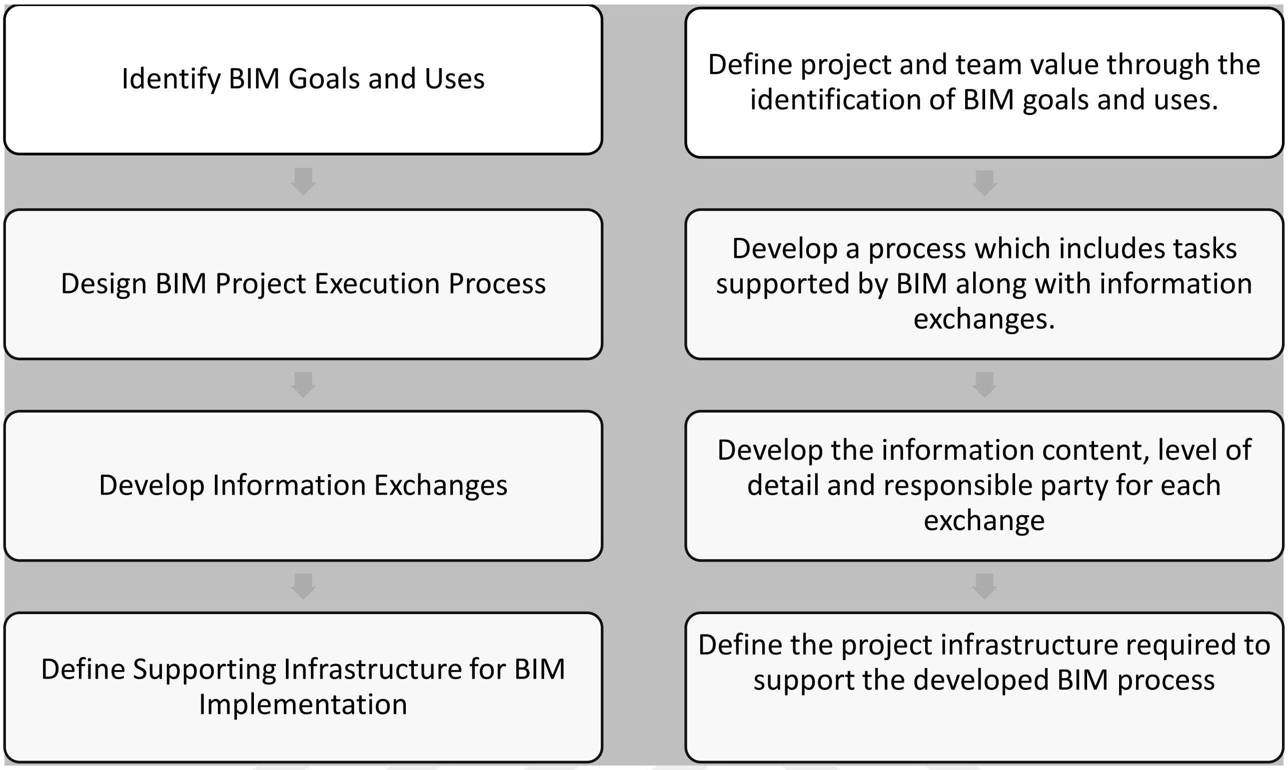


Figure 21: BIM Project Execution Planning Procedure (adopted from NBIMS-US.V3 – National BIM Standard – United States)

BIM Execution Plan content according to NBIMS-US V3 which has also been referred in preparation of the IGA BIM Execution Plan is given in Table 4.

Table 4: BIM Execution Plan Content

BEP SECTION	***SECTION NAME***
SECTION A	BIM PROJECT EXECUTION PLAN OVERVIEW
SECTION B	PROJECT INFORMATION
SECTION C	KEY PROJECT CONTACTS
SECTION D	PROJECT GOALS / BIM USES
SECTION E	ORGANIZATIONAL ROLES / STAFFING
SECTION F	BIM PROCESS DESIGN
SECTION G	BIM INFORMATION EXCHANGES
SECTION H	BIM AND FACILITY DATA REQUIREMENTS
SECTION I	COLLABORATION PROCEDURES
SECTION J	QUALITY CONTROL
SECTION K	TECHNOLOGICAL INFRASTRUCTURE NEEDS

SECTION L	MODEL STRUCTURE
SECTION M	PROJECT DELIVERABLES
SECTION N	DELIVERY STRATEGY / CONTRACT
SECTION O	ATTACHMENTS

In a holistic manner, IGA BIM department have begun integrating the BIM Execution Plan with the project designers via using interface management procedure. A 30-month scheduled plan has been prepared covering a lifecycle which includes a strategy declaring design development, construction documentation, and operations stages respectively.

4.2.1.2. BIM Implementation Strategy

Productivity in design and construction is considerably enhanced by facilitating BIM for the coordination between contractor, designers, engineers and consultants where on time and correct information flow is provided. Designers and engineers responsible for structural, architectural, infrastructural, mechanical, electrical and plumbing (MEP) disciplines and baggage handling system (BHS) which several of them are based in various countries was effectively managed on the BIM platform by weekly coordination meetings held in the BIM Rooms. The BIM department provides the appropriate project data to anyone who wants it at any time. In Figure 22, BIM Implementation Strategy for IGA is illustrated.

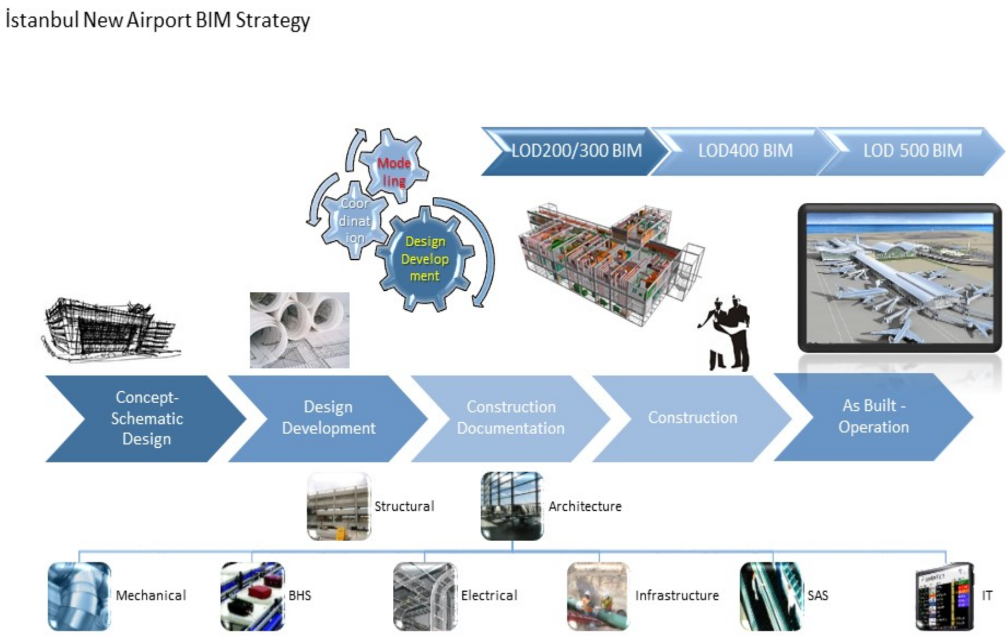


Figure 22: IGA BIM Strategy Chart

Essentials of BIM Implementation in IGA includes and not limited to below topics in general;

- Intelligent design of all disciplines
- Good planning and tracking of delivery of the design drawings
- Quality checked, clash-free and as-engineered BIM models of all disciplines
- Fully BIM compatible, digitally reviewed shop drawings before site delivery
- On-time and continiuous delivery of drawings through mobile devices and BIM cloud environment
- Intelligent handling of design change requests and revisions in costly and timely perspective
- Strict management of subcontractors and claim detention

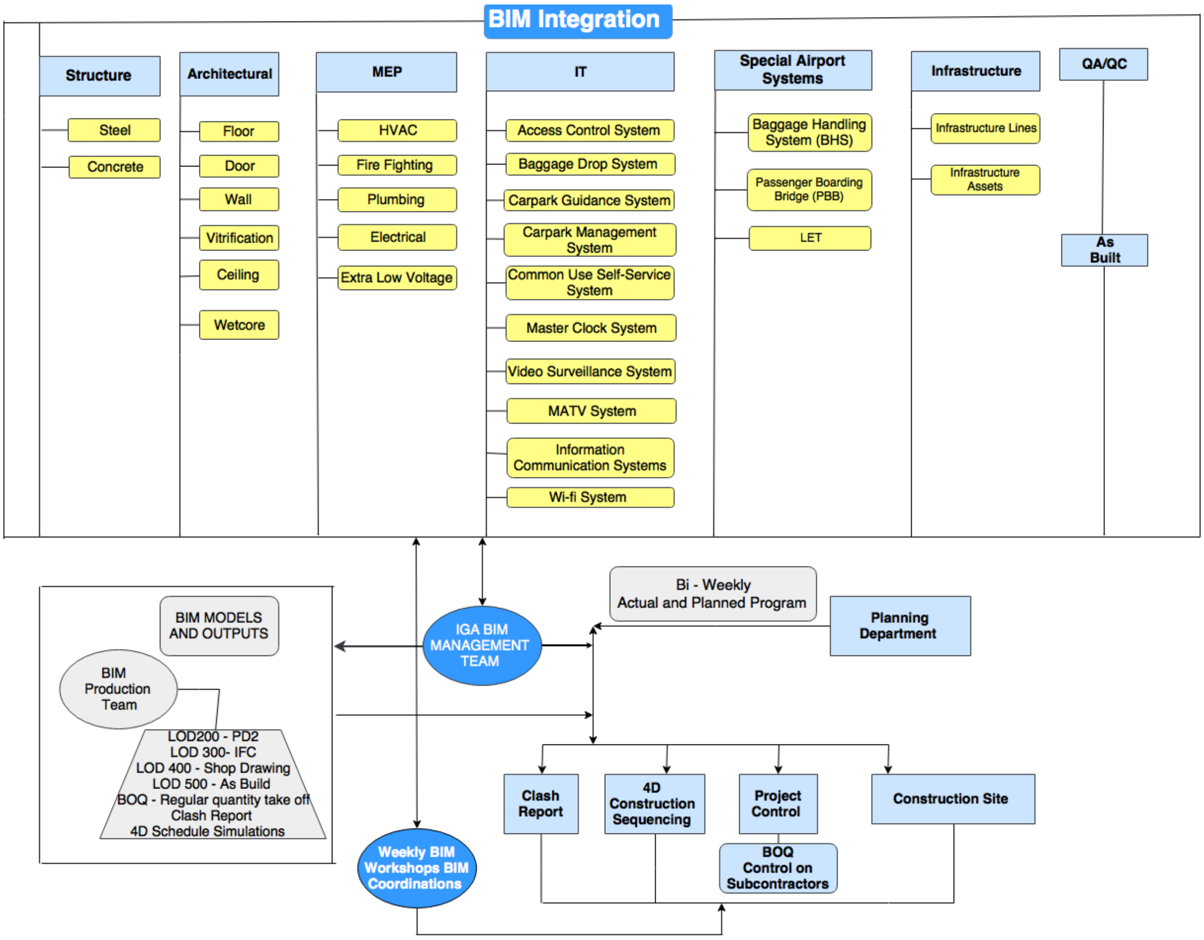


Figure 23: IGA BIM Implementation Workflow

There is a well tailored BIM implementation workflow which puts BIM management team in the core of project delivery processeses, which is one of the key factors of BIM implementation success in IGA. In Figure 23, IGA BIM implementation workflow is illustrated.

4.2.2. BIM Teams and Technological Resources

Establishing a concrete infrastructure for an effective and efficient BIM implementation in a large scale project, people and technology are two of the key factors. In this chapter, BIM resources in terms of people and technology is explained.

4.2.2.1. BIM Teams and Key Responsibles

One of the key factors of successful project delivery is building an effective BIM team. In order to provide the best BIM implementation in IGA, there are 4 teams within the BIM department including Management Team, Technical Office Team, Site Engineering Team and Modelling Team.

4.2.2.1.2. BIM Management Team

BIM Management team is the core group for BIM implementation and execution. Establishing of the BIM infrastructure, assigning key responsibles, execution and monitoring of BIM activities are management team responsibilities. Within the management team, roles and their responsibilities are defined in Table 5.

Table 5: Roles and Responsibilities in IGA BIM

Role	*Responsibilities*
BIM Director	Creation and execution of project BIM strategy
	Review, monitor and approve overall BIM progress
	Manage and provide necessary support for BIM Implementation on the overall project
	Report BIM delivery to the CEO and the Board
BIM Manager	Creation and maintaining the BIM Execution Plan
	Attending weekly BIM coordination meetings and BIM workshops
	Performing regular QA/QC checks on discipline models to ensure compliance with project BIM standards
	Ensuring the BIM Project Execution Plan is followed through the project duration on a daily basis
BIM Engineers	Establish communication between disciplines and BIM production team.
	Follow RFI and Clash procedures.
	Manage common data environment
	Ensure up-to-date project information is transferred to BIM production

4.2.2.1.3. BIM Technical Office

BIM Technical Office consist of architects and engineers that are responsible for quality checking of multi-disciplinary model coordination, executing engineering reviews for design drawings, deriving quantity take offs and verifying on schedules and cost estimations with other technical offices.

4.2.2.1.4. BIM Site Engineering Team

BIM Site Engineering Team is mainly responsible for checking if site installations are compatible with the coordinated BIM model, communicating with technical departments and subcontractors on site and ensuring the coordinated model is being constructed on site, creating and assigning issues if otherwise. Digital project controls, QA/QC, Test and Commissioning processes are also responsibilities of the site engineering team.

4.2.2.1.5. BIM Modelling Team

BIM Modelling team is an outsourced drafting team responsible for creating and submitting the multi-disciplinary BIM model meeting the requirements given by the contractor. At the peak, modelling team consist of up to 40 individuals which are technicians, architects and engineers.

4.2.2.2. Technological Resources

Technological resources including hardware and software are as important as a capable team for BIM execution. Hardware and software resources used in Istanbul Airport is a variation and a decision of the managers considering the size of the project, quality and quantity of the design, engineering and construction partners and so on.

In terms of software, Autodesk products are fully integrated through the project. In terms of information management; Autodesk Vault and Autodesk Buzzsaw are being used. In later phases of the project, next generation BIM360 applications are replaced with the old cloud applications. 3D/4D modelling and coordination environment is provided by Revit and 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, Next Gen BIM360) apps. Project team communication is realised with Basecamp which is a project management software enables effective collaboration between parties. Hardware and software resources are listed in Table 6 below.

Table 6: Hardware and Software Resources for BIM

Hardware Resources	Software Resources
BIM Room-1 capable of handling remote conference video and voice calls or round table meetings. 3m*9m video Wall and smart whiteboard included.	Autodesk AEC Collection
BIM Room-2 capable of handling remote conference video and voice calls or round table meetings. Smart whiteboard included.	BIM360 (old and next gen) modules
At least 2 super computers that can handle 30+ GB navisworks master model. These computers have at least 256GB of RAM, 8TB of storage at the time when the case study research was done. Workstations with Intel i7 or Xeon, 64GB RAM, 2TB HDD for the rest of the BIM team.	Facility Management softwares
Dedicated server for BIM Model coordination, Facility Management software and other requirements in Tier III Airport Data Center.	Project management softwares
Apple iPad Pros Wifi + Cellular for mobile BIM.	Primavera
2 robotic total stations.	Tekla
1 Laser scanning device with software	Rhyno

4.2.3. Continuous Training and Technical Support

In order for contractor and subcontractor technical teams to be trained and supported with BIM tools usage, continuous training and technica support is utilized by BIM Team. Trainings are held by weekly for various departments and various fields of BIM including tools such as BIM360 mobile training, Navisworks, Revit and workflows such as quality control, test&commissioning, design approval processes. In figure 24 weekly training program can be seen for Istanbul Airport, utilized during the construction works.

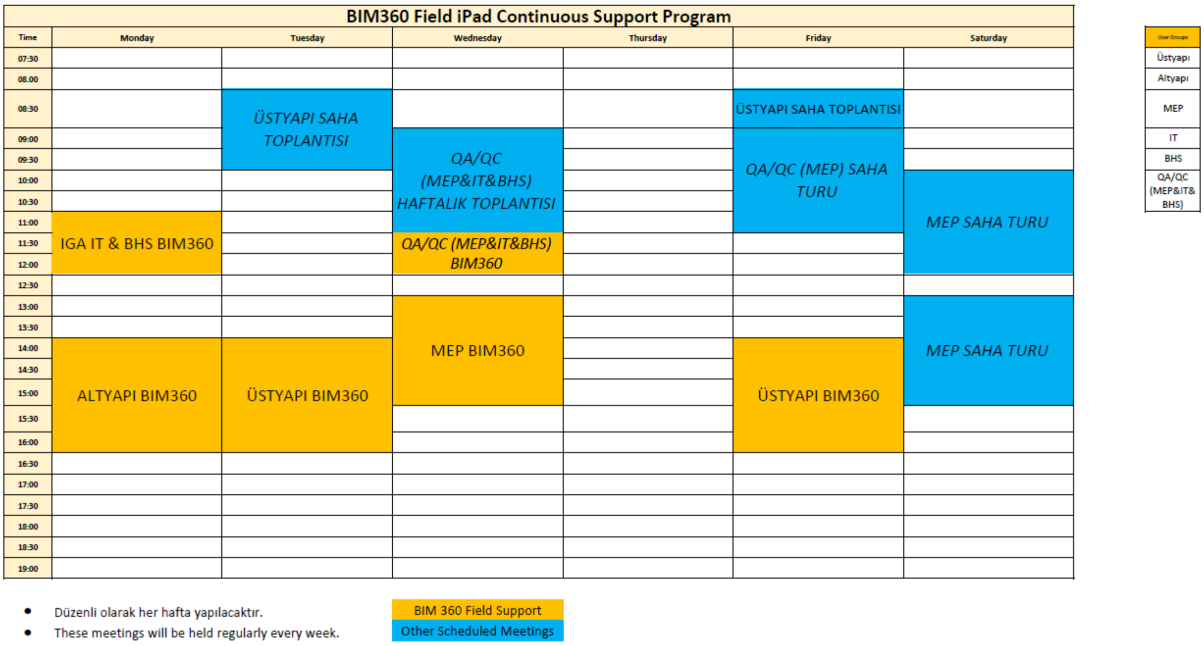


Figure 24: IGA BIM Continuous Training Program

4.3. Design & Engineering Management

BIM enables the knowledge, pushes the project teams forward by creating the platform of true collaboration. IGA BIM Director stated that his key role is to develop and execute BIM implementation at all stages, starting with design, and proceeding with construction and operation while managing the use of the correct technological processes and the transformation of people. Within the project, BIM is a platform for the engineering and coordination processes of all disciplines including structure, architecture, MEP, ICT, special airport systems and so on. This massive coordination is quite extraordinary considering the project size, complexity and the challenging project timeline. In the execution of engineering and design, BIM plays a strategic role in catalyzing the improvement of the efficiency of design and construction, which is a key driver to be on time and even ahead of production on site.

It is also important to be aware of the fact that BIM's success is not only due to its technological advantages, but also because of how it brings people together in a collaborative virtual environment. That is why individuals and processes that are followed by technology are the key things.

Figure 25: BIM Room

In an extremely complex project where seperate international companies and individuals are involved in design, collaboration among all of them and coordination of the project requires a very structured and holistic approach. In IGA, designers and subcontractors both international and Turkey-based have been connected in BIM Room, which is an environment for coordination and taking decisions in a fast, straightforward manner. In BIM Room, regular and pop up coordination meetings held providing very efficient results thanks to the BIM environment people involve in. Both for BIM Team and project individuals, BIM Room has been the problem-solving point with integrating key people no matter where they are. BIM production and coordination workshops are being held in BIM Room in a collaborative environment. Below is the workshop schedule for IGA BIM.

BIM WORKSHOPS SCHEDULE					
Time	Monday	Tuesday	Wednesday	Thursday	Friday
	11.1.2016	12.1.2016	13.1.2016	14.1.2016	15.1.2016
07:30					
08.00					
08:30		BIM Production Meeting Attendees: BIM Management, BIM	BIM Production Meeting Attendees: BIM Management, BIM	BIM Production Meeting Attendees: BIM Management, BIM	BIM Production Meeting Attendees: BIM Management, BIM
09:00	Weekly BIM Production Meeting Attendees: BIM Management, BIM Production			**General BIM Coordination Meeting** Attendees: BIM Management, Design Managers From All Disciplines, Design Consultants From All Disciplines	
09:30					
10:00					
10:30				**Airside-Sitewide BIM Coor. Workshop** Attendees: BIM Management, Design Managers From Relevant Parties, Design Consultants From Relevant Parties	
11:00					
11:30					
12:00					
12:30					
13:00					
13:30	**Terminal BIM Coor. Workshop** Attendees: BIM Management, Design Managers From Relevant Parties, Design Consultants From Relevant Parties	**Carpark BIM Coor. Workshop** Attendees: BIM Management, Design Managers From Relevant Parties, Design Consultants From Relevant Parties	**Piers BIM Workshop** Attendees: BIM Management, Design Managers From Relevant Parties, Design Consultants From Relevant Parties	**Terminal BIM Coor. Workshop** Attendees: BIM Management, Design Managers From Relevant Parties, Design Consultants From Relevant Parties	**Piers BIM Workshop** Attendees: BIM Management, Design Managers From Relevant Parties, Design Consultants From Relevant Parties
14:00					
14:30					
15:00					
15:30					
16:00					
16:30					

Figure 26: IGA BIM Workshop schedule

BIM coordination issues, RFI's and clash resolutions are subject for BIM Coordination Workshops. Attendees of workshops are BIM management, IGA design managers for relevant disciplines and design consultants for relevant disciplines. For the time being there are six workshops scheduled weekly as shown in Figure 26. More workshops can be added when needed.

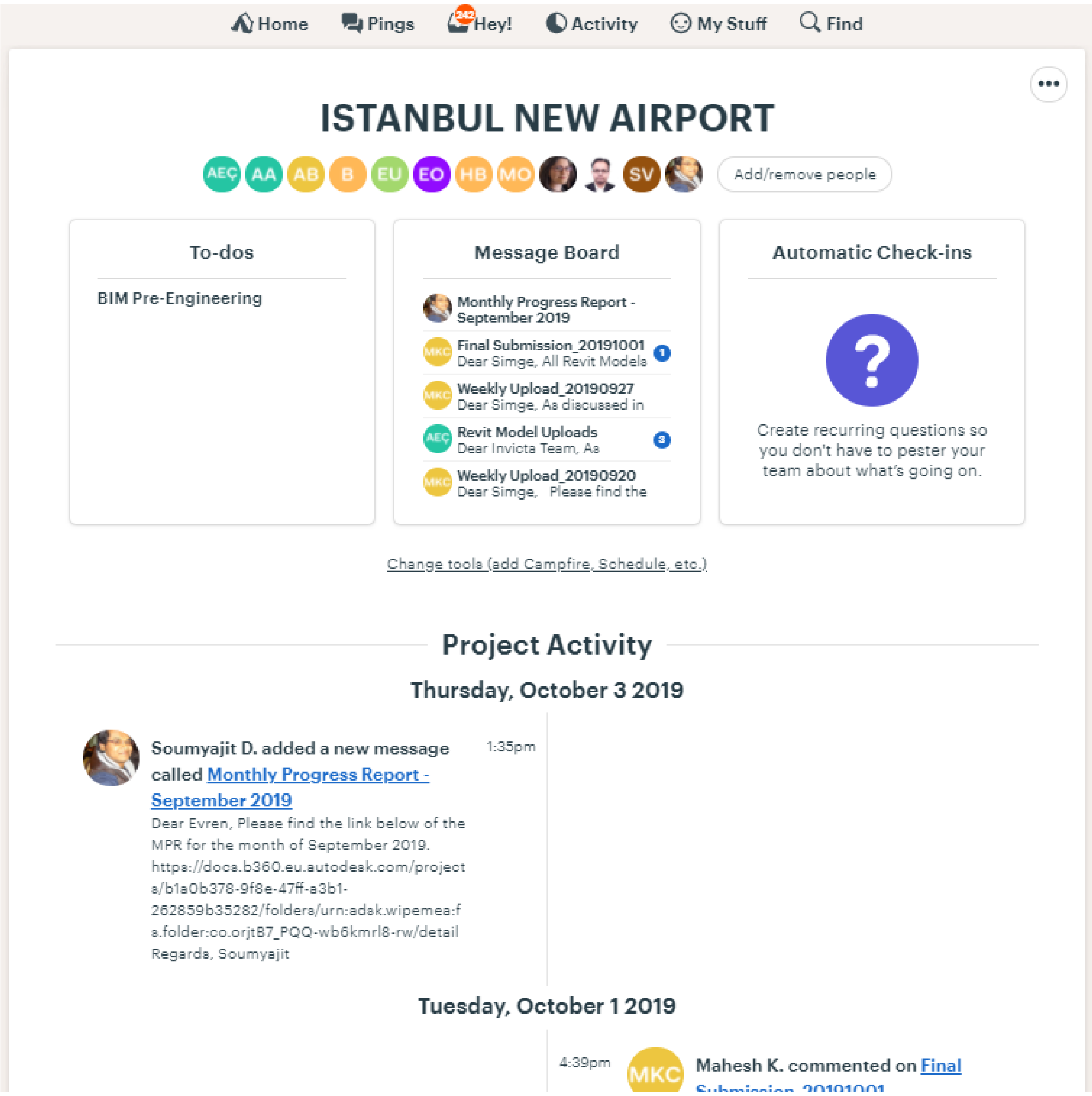


Figure 27: Basecamp Project Team Management Software Screenshot

Project team management is done with a software being used internally by BIM Management Team and BIM Modelling Team which enables real time collaboration enabling efficient communication. Basecamp is used for BIM model coordination issues, RFI coordination and other design & engineering related collaboration. In figure 27 a screenshot from basecamp software can be seen.

4.3.1. BIM Model Production and Development

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.

As a model development approach, project needs are at the core. As the project proceeds to the next phase, the BIM model also develops to the next phase to be ready to deployed in the necessary coordination processes throughout the project. Hence, in Figure 28, it can be seen there are 3 phases for model development including Construction Model, Commissioning

Model and Operational Model.

✓ Design / Coordination ✓ Clash Detection ✓ SD Production & Control ✓ Site Engineering & Supervision ✓ Project Control ✓ Quality Control ✓ Room Data Sheets	✓ Room & Equipment Tagging ✓ Commissioning Model Data Correction (BIM Assure) ✓ SD Integration (2nd & 3rd fix eq.) ✓ MAF Classifications / Equipment Attributes	✓ Asset Management ✓ Work Request Allocation ✓ Process Automation & Analytics ✓ Business Process Development ✓ Incident Management ✓ 3rd Party Integration ✓ Facility Booking

Figure 28: BIM Model Development Phases

BIM modeling scope includes modeling, coordination and update of architecture, concrete, structural steel, MEPF-IT, BHS, SAS, LET systems from LOD200 to LOD500 for a total area of 2.084.746 m^2 which consist of a main terminal, 5 piers, carpark, utility center and ATC tower. Additionally, LOD100 modeling of all airside and landside buildings and integration of Turkish Airlines facilities. In figure 29, a view from Navisworks Master Model of IGA can be seen.

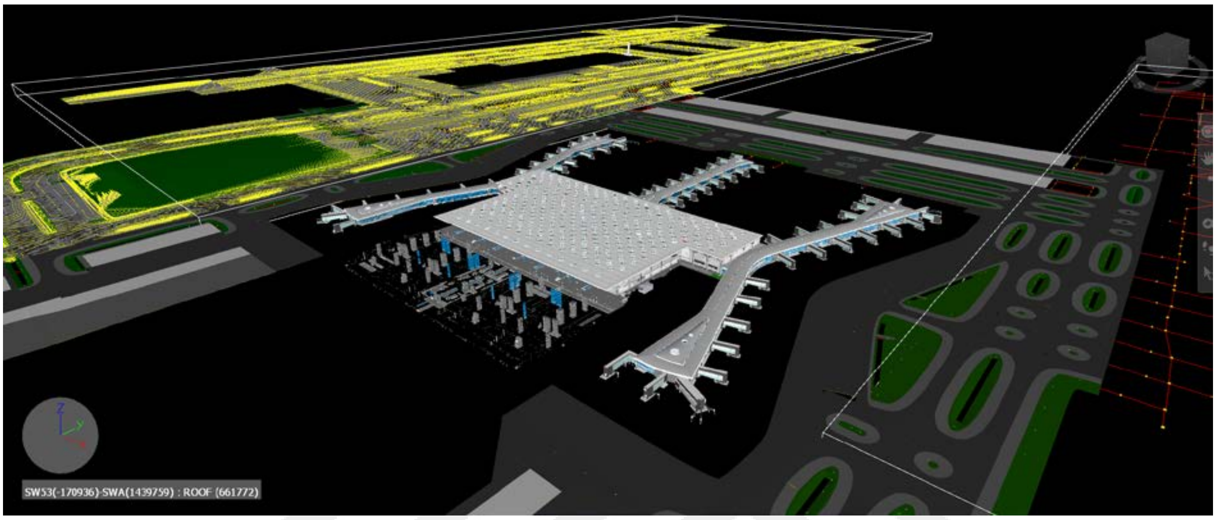


Figure 29: Master BIM Model view of IGA

In terms of infrastrcutral systems, runways, taxiways, apron and surface models are integrated to BIM model. Modeling, clash analysis and cross coordination of infrastructure network in airside and landside areas are done in the scope of BIM during the project with an approx. Modelling area of 14.000.000 m^2. Inftrastructure model consist of Air Passenger Mover (APM) Line, Galleries and Tunnels, Drainage, Electrical Network, Fire Hydrant, Fuel Hydrant, Domestic Water, Grey Water, Irrigation, IT Network. Figure 30 shows the supporting buildings exist in the master model.

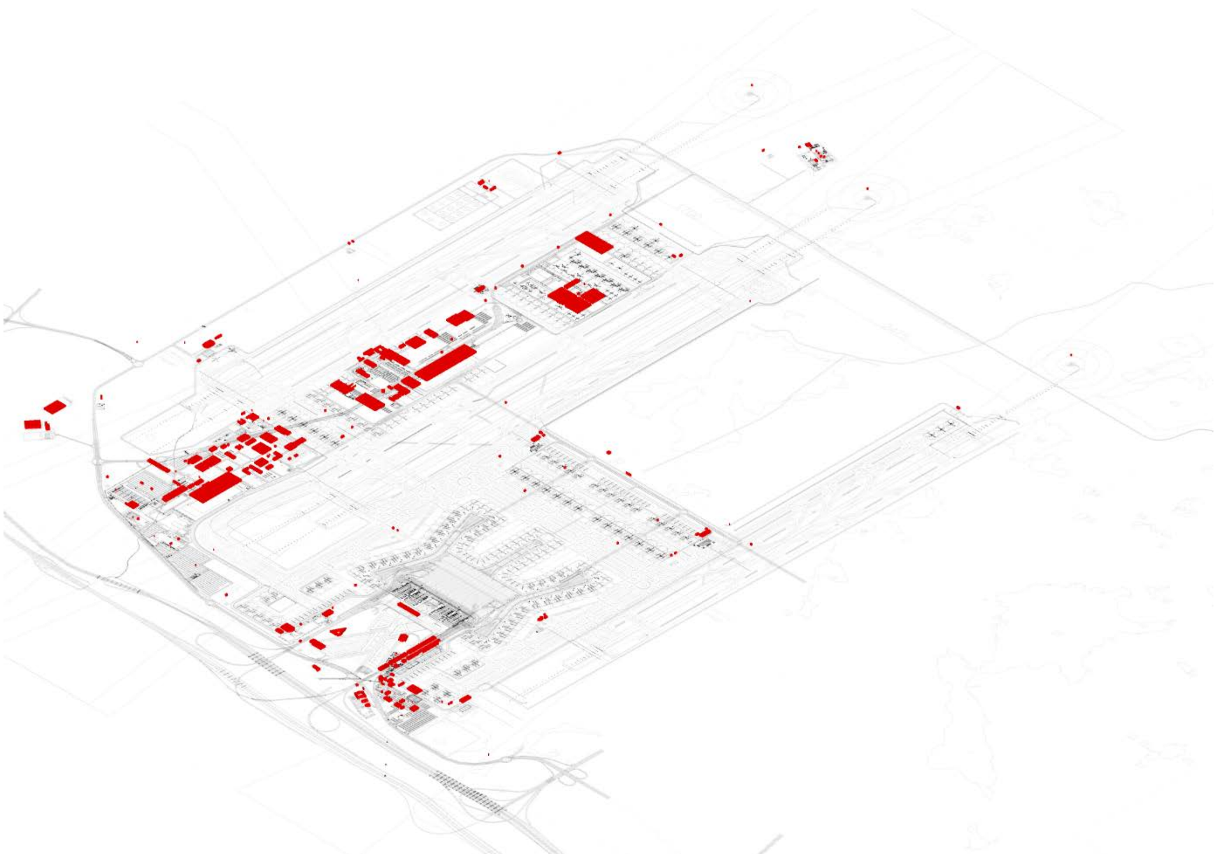


Figure 30: Other Buildings in BIM modelling scope of IGA

There is a massive multi-dimensional design and engineering coordination with the participation of all shareholders including designers, engineers, architects, consultants, contractors and subcontractors. In Figure 31 MEP-IT-SAS coordinated system model of Terminal Building can be seen.

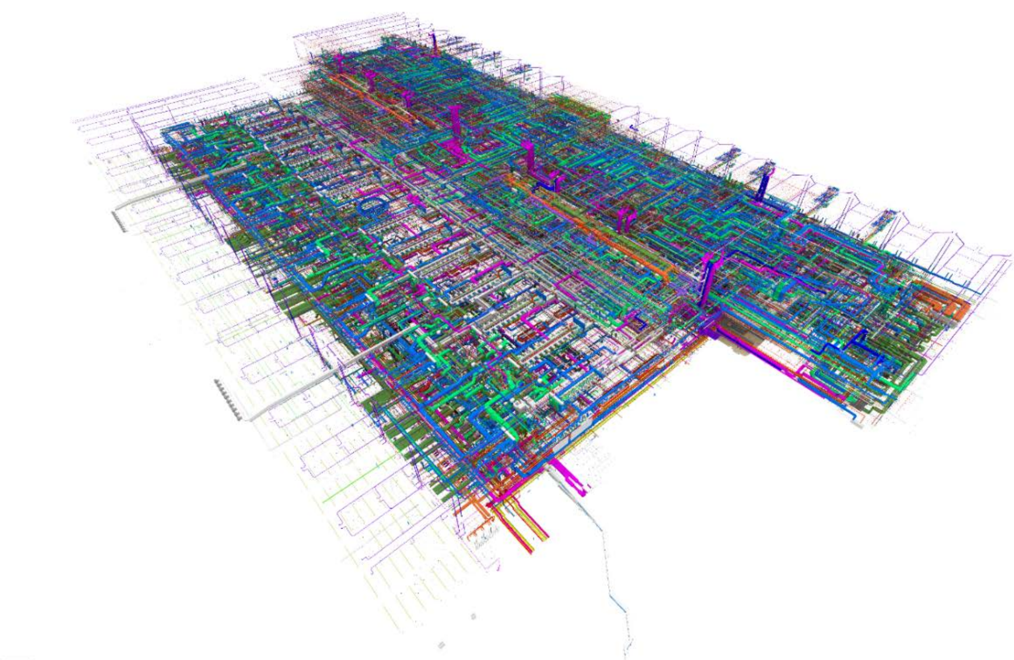


Figure 31: Terminal Building MEP-IT-SAS Coordinated System Model

One of the most important assets of an airport is Air Traffic Control (ATC) tower. ATC tower is a critical building for smooth airport operations hence it is very important for this building to be delivered on time for project closure. In Figure 32, steel structure and MEP-IT-SAS systems coordinated BIM model can be seen.

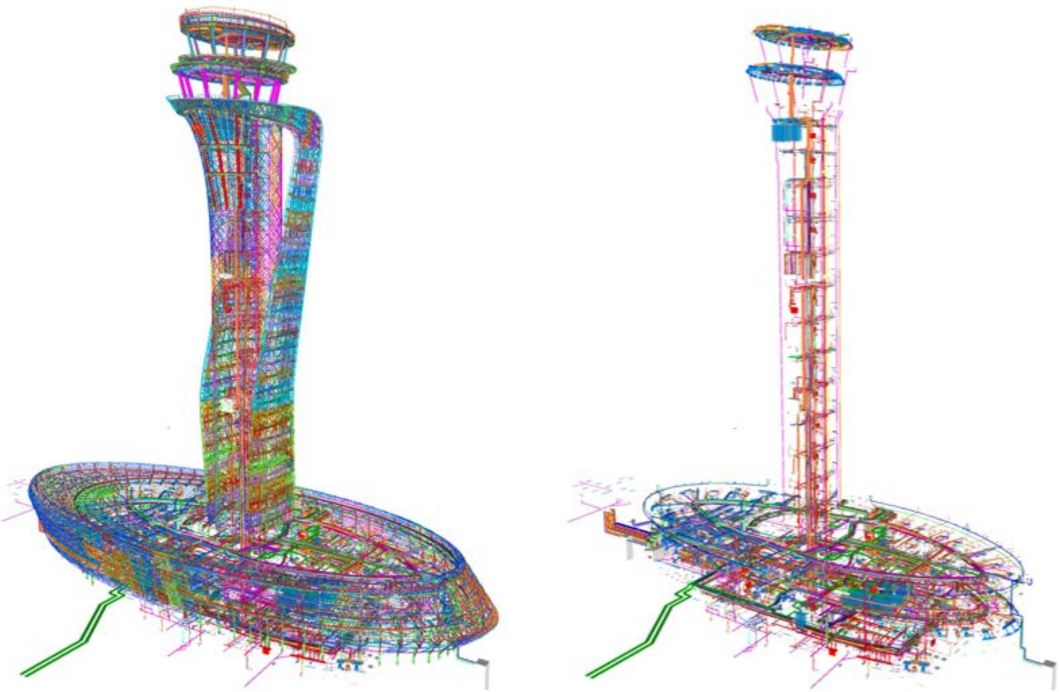


Figure 32: Air Traffic Control (ATC) Tower Structural and MEP-IT-SAS coordinated system models

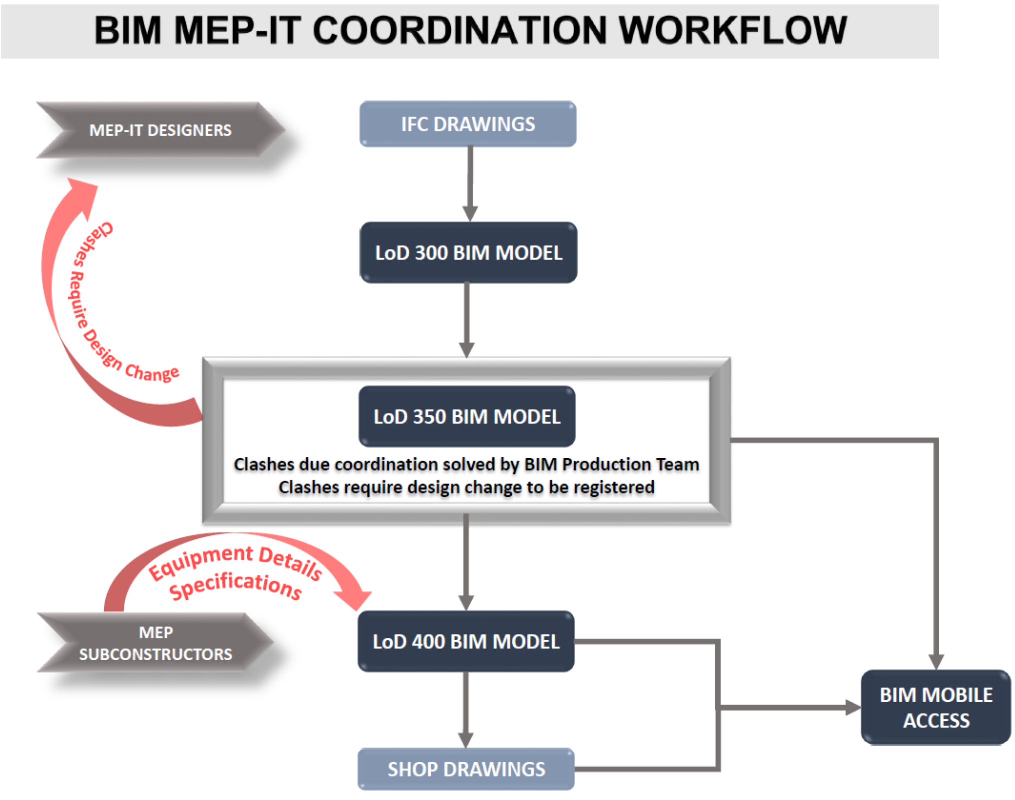


Figure 33: BIM MEP-IT Coordination Workflow

Publishing and exchanging the correct data is very important at all. In IGA, cloud based data management tools are being use to publish models, coordination documents and other related information via Autodesk Buzzsaw and Autodesk Vault applications. It is mostly crucial for such a complex project to reach any information without wasting time. With BIM implementation of those tools, waste of time and waste of information is minimised.

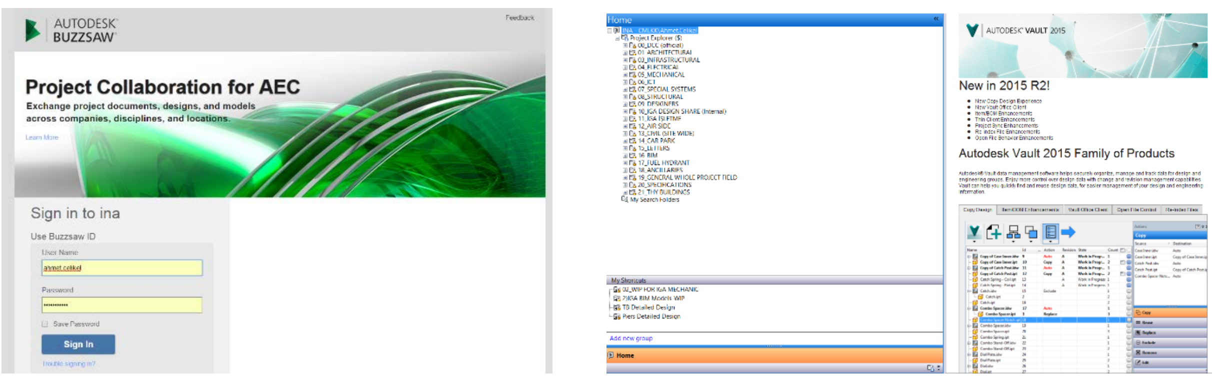


Figure 34: Autodesk Buzzsaw and Vault is being used for Information Exchange

LOD matrixes and LOD definitions are done by the subcontractor of BIM which was included in the BEP and subject to the contractual issues. Figure 35 shows a sample for LOD Matrix Index of IGA BIM.

LOD MATRIX INDEX

ARCHITECTURE	STRUCTURE	HVAC	PLUMBING & FIRE PROTECTION	ELECTRICAL
WALLS	CONCRETE COLUMN	AHU	NRV	CABLE TRAY
DOORS	STEEL COLUMN	ATTENUATER	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 SPINKLERS	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

LOD MATRIX INDEX - BEP ANNEXURE A (POINT NO 12.2)

Figure 35: LOD Matrix Index

Every single item in the LOD Matrix Index are detailed seperately in order to give information on which equipment and system will be modelled in what detail. In Figure 36 a sample LOD Matrix of a mechanical equipment is shown.

LOD MATRIX

PROJECT NAME	ISTANBUL NEW AIRPORT
INVICTA PROJECT CODE	2015-008
ITEM DESCRIPTION	PUMP
ITEM CATEGORY	MECHANICAL EQUIPMENT
ITEM CODE	PMP
REVISION	A

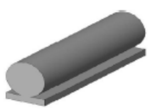
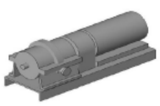
INFORMATION CATEGORY	INFORMATION ITEM	LOD 200 YES/NO	LOD 200 DESCRIPTION/SNAP	LOD 300 YES/NO	LOD 300 DESCRIPTION/SNAP	LOD 400 YES/NO	LOD 400 DESCRIPTION/SNAP	LOD 500 YES/NO	LOD 500 DESCRIPTION/SNAP
PHYSICAL PROPERTIES	Length	Y	Generic Element : schematic layout with approximate size/shape/location of 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/filed 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	N		Y		Y		Y	
	Nominal Size	N		Y		Y		Y	
LOCATION PROPERTIES	Building ID	N		N		Y		Y	
	Building Name	N		Y		Y		Y	
	Floor ID	N		N		Y		Y	
	Floor Name	N		Y		Y		Y	
	Zone/Space Name	N		Y		Y		Y	
	Zone/Space ID	N		N		Y		Y	
	Elevation	Y		Y		Y		Y	
ANNOTATION PROPERTIES	System Abbreviation	Y		Y		Y		Y	
	Sub-System Abbreviation	N		Y		Y		Y	
	Mark	Y		Y		Y		Y	
QUANTIFICATION PROPERTIES	BOQ Reference No	Y		Y		Y		Y	
	WBS number	N		N		Y		Y	

Figure 36: LOD Matrix sample for Mechanical Equipment

Inconsistencies in the 2D design drawing and omitted information are collected through raised RFIs from the BIM Production team to the relevant disciplines. RFIs are subject to major design problems, so RFI is the precursor prior to the detection of conflicts. BIM management logs all RFI and discipline responses as open/closed. Open RFIs in BIM Coordination Workshops are an agenda item. For developing PD designs at the IFC level, RFIs are critical. Clash detection is an important part of the quality control process for design and construction model. By the leadership of BIM team, design teams from each discipline are involved in the solution of clashes in order to ensure the model is fully coordinated and clash-free. Generating the clash reports is in the scope of BIM subcontractor. After issuing the clash report, IGA BIM team filters and groups the clash report and assign them to the relevant parties if necessary. Solved clashes are again reviewed by IGA BIM team and verified if approved. Huge number of clashes mostly does not need to be assignes, where there are exceptions of clashes require design changes or special attention and very major. Remaining clashes are solved with pre-defined tolerances and clearances by IGA BIM subcontractor with the directives of IGA BIM team until the model is clash-free. During clash solving, RFI forms (Request for Information) are issued by the production team where there are missing information or difficulty about a coordination issue. RFI workflow is pre-determined by IGA BIM Department is applied with relevant design teams involved. Answers to RFI forms are again sent to the production team and coordination progress is going on. In Figure 37 there is a sample from RFI list of BIM Department.

REQUEST FOR INFORMATION (RFI) SUBMITTALS LOG

INVICTA Project Code: 2015-008
RFI Log Ref : INV / INA / RFI / LOG / 2016 / 001
Last Updated on: 1/29/2016 21:13

						ACTUAL				
SEQ	RFI SUBMITTAL NO.	REV NO.	DISCIPLINE	RFI DESCRIPTION	AREA/LOCATION	DATE OF SUBMISSION	RECEIVED DATE	LAG DAYS	STATUS	RESPONSE RECEIVED
10	INV-BIM-MEPF-00009	A	MEPF	MEPF services running in both BHS Mezzanine and arrival level in Terminal building inside area TB1 and there is no information for slab arrangement in this location and the relevant structure drawing (If any) is missing. So we couldn't identify the extent of levels in this area to run the MEPF service. Kindly provide service levels in this area or any sutable section.	TB/ (BHS Mezzanine) & (Arrival)	1/4/2016	1/6/2016		CLOSED	AHU Ducts which serving BHH & International arrivals concourse are passing from the bottom of Level E slab (Level D ceilling), schematics attached.
11	INV-BIM-MEPF-00009	B	MEPF	We need the service arrangement showing Level D and Level Y. At the moment RFI reply showing the service arrangement schematic between level E andlevel Y . There is missing slab between level D andblevel Y as per our original query as there is no slabdivision in structure drawing.	TB/ (BHS Mezzanine) & (Arrival)	1/7/2016		22	OPEN	
12	INV-BIM-MEPF-00010	A	MEPF	1. Riser size information missing for mechanical pipes. The reference drawing is clouded to reflect the risers. 2. There are condensate drain drop size missing/ no riser diagram for condensate drain pipe.	ALL AREA	1/4/2016		25	OPEN	
13	INV-BIM-MEPF-00011	A	MEPF	Fire protection pipe and sprinkler location is clashing with structural elements in many location.	TB/BASEMENT	1/4/2016		25	OPEN	
14	INV-BIM-MEPF-00012	A	MEPF	Duct and grill size missing in many areas in mezzanine level terminal building. We have clouded typical areas in the attached layout for easy reference.	TB/Mezzanine	1/5/2016		24	OPEN	
15	INV-BIM-MEPF-00013	A	MEPF	1. Pipe size changes in the same pipe without any branch distribution. Please refer the attached snapshot for more info. 2. Sump pit location clouded in snapshot missing in structure drawing. Please refer to relevant snapshot atatched. 3. Valve legend missing in domestic hot water pipes as marked in the relevant snapshot.	TB/BASEMENT	1/5/2016		24	OPEN	
16	INV-BIM-STRC-00014	A	Structural	In the drawings of mockup area on grid NE26, Beam tags are showing width as 200, however its drafted 300 wide. Please confirm which one needs to be followed. Snapshot is enclosed & dwg reference no are as under:- INA-B01-01-01-03-D-FC-DWG-STR-10-1001-002-R00 INA-B01-01-01-03-D-FC-DWG-STR-10-1101-001-R02	PB - PB1-3 / D	1/6/2016	1/13/2016		CLOSED	Response By PROTA : The width is revised to 300mm.

Figure 37: Sample RFI List of BIM Department

In a BIM model, clashes can be taken into consideration as hard or soft clashes. A hard clash is where the same area is occupied by two or more physical objects. For example, if a mechanical ductwork is located where there is a structural member, an example of a hard clash would be exist. By re-routing the duct, shifting the structural member, or making a room for the duct in the structural member's web, such a clash may be resolved. (GSA BIM Guide 07 – Building Elements, 2016)

If the occupance of two or more objects happens with the required clearances, tolerances or access spaces, it can be considered as a soft clash. As an example, if a piece of equipment is positioned so that it blocks an access door, does not allow the access door to be completely opened, or fills the room where a construction operator or technician will have to operate. (GSA BIM Guide 07 Building Elements, 2016).

In Figure 38 a sample clash report derived from Navisworkds Clash Detector, which is systematically used to determine multi-disciplinary clashes can be seen.

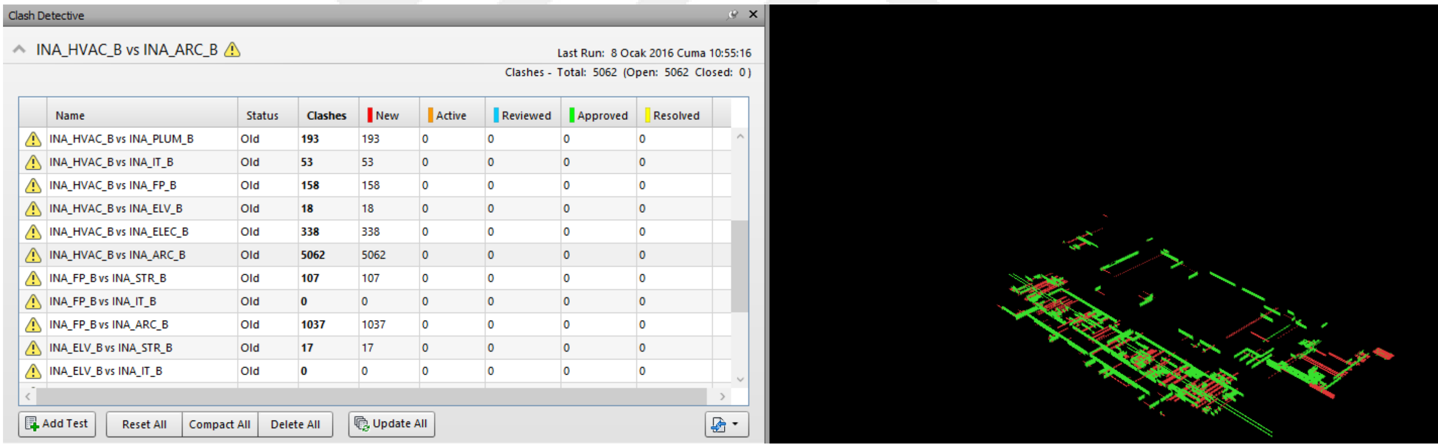


Figure 38: Sample Multi-discipline Clash Report

In the process of coordination, Autodesk Navisworks is being used in order to view the model and make decisions over clashes or unresolved issues. When doing this, viewpoint preference of Navisworks is widely used. Viewpoints are the views of the model of a previously saved location. One can mark-up on those viewpoints in order to share the resolution with someone else. The share process is done by .xml files which is commonly used. It is possible to share the saved viewpoints by sharing .nwf Navisworks file format if there is a change done into any model element such as shifting or rescaling. Below there is a sample viewpoint breakdown from a coordination workshop, where issues are grouped by category as MEP, Arch and BHS team related.

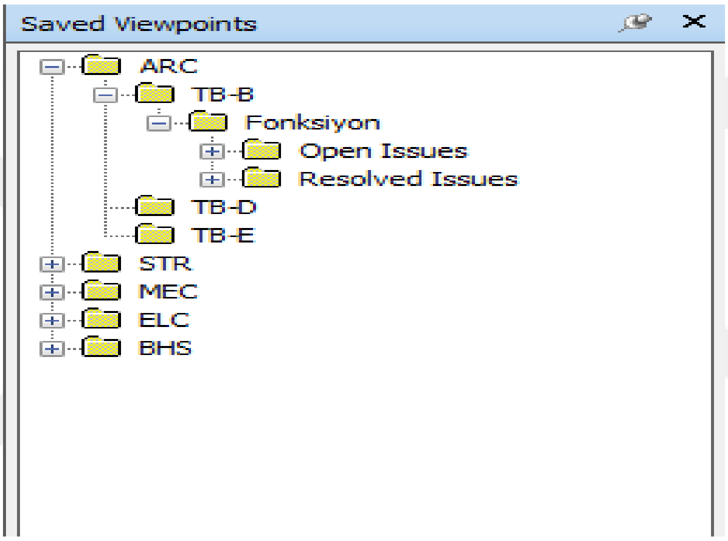


Figure 39: An example of viewpoint grouping

In figure 40, there is an example viewpoint shows digital representation of coordinated MEP systems and markups for coordination.

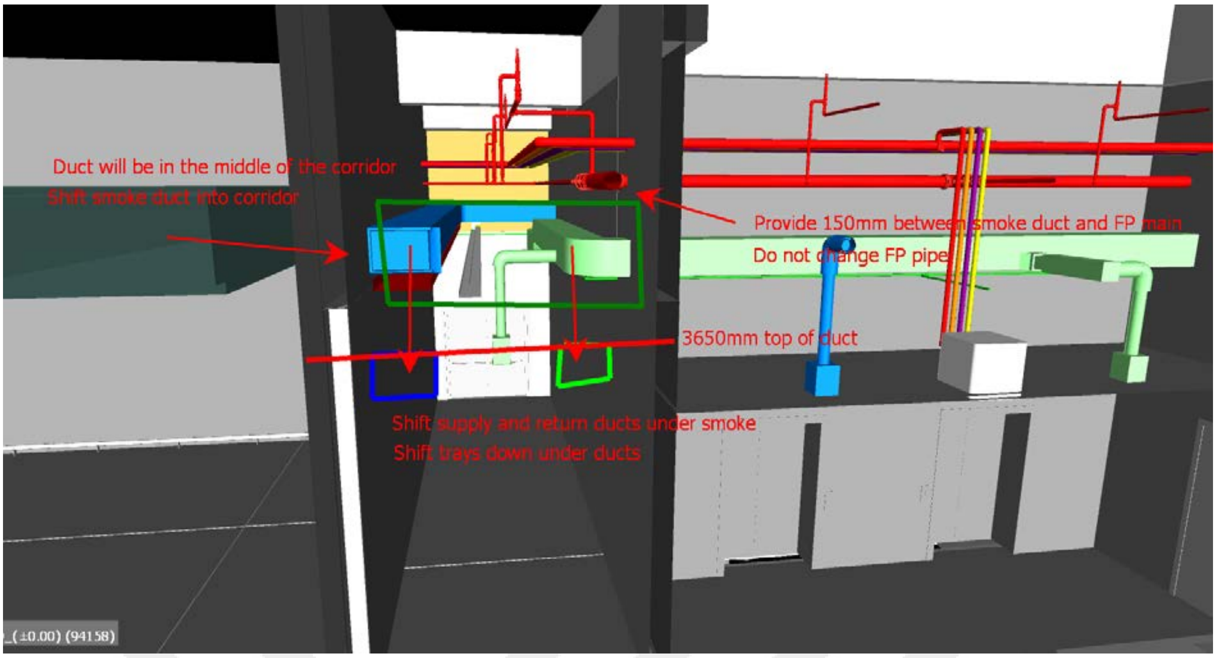


Figure 40: A saved viewpoint during coordination workshops

More than 600,000 disputes have been settled so far in the IGA Project, saving time and money and avoiding on-site rework. It also avoids any unexpected claims, time extensions and cost overruns. A research previously held in IGA that shows solved clashes and the impact of the solutions of clashes to the project in terms of time and cost.

Table 7: Clash detection analysis and related time and cost savings achieved

TERMINAL	Number of Clashes	Clash depency Coefficient	Number of Clashes with dependencies	Per Clash /Man*day	Total Savings Time (Day)	Labor Cost (35€ /Per Day)	Reconstruction (Avg:€500)	Total Cost Saving
BHS vs MEP Clashes	52.305	0,25	13.076	*45 days*10 men	5.884.200	€205.947.000,00	Negligible	€205.947.000,00
MEP vs MEP Clashes	240.176	0,33	79.258	*21 days*5 men	8.322.090	€291.273.150,00	Negligible	€291.273.150,00
MEP vs ARCH & STRC	76.275	0,5	38.138	* 2 days*2 men	152.552	€5.339.320,00	€76.276.000,00	€81.615.320,00
BHS vs ARCH&STRC	96.750	0,5	48.375	*2 days*2 men	193.500	€6.772.500,00	€96.750.000,00	€103.522.500,00
PIERS								
MEP vs MEP Clashes	49.521	0,33	16.342	*21 days*5 men	1.715.910	€60.056.850,00	Negligible	€60.056.850,00
MEP vs ARC&STRC	86.891	0,5	43.446	*2 days*2 men	173.784	€6.082.440,00	€86.892.000,00	€92.974.440,00
TOTAL	601.918		238.635		16.442.036 man-days	€575.471.260,00	€259.918.000,00	€835.389.260,00

In Table 7, using the normalized values, cost and time savings are estimated. In other words, dependence between clashes is also taken into consideration: once a conflict is resolved, due to significance and similarity between them, several other clashes are also subsequently solved. For example, in the combined BIM model, when a major clash is explored and resolved, there might be four or five other clashes that are also resolved, which are normalized with 0.25 constants in advance, whereas medium clashes are normalized with 0.33 constant and minor clashes with 0.5 constant. As a consequence, the normalized numbers of crashes are determined accordingly. A conflict with its dependence clashes is regarded as one conflict in the normalized clash numbers. This brings us to normalized clashes in total, which so far is 238,635 clashes all together.

It was possible to save 442,036 days of time and £835,389,260 of project costs as per digital test & commissioning process, equal to percent 10 of the overall budget for the IGA project phase 1. If the raw clash numbers (601,918) are taken into account, this figure would be about £2.5bn, which would be the case of time delays and financial strain if conventional approaches had been used by the project. In terms of waste elimination and value generation, these figures already illustrate the synergies between BIM and lean.

In a typical practice-based design and development scenario, anticipating the en-counter of those 600,000 clashes will typically cost about EUR 2.5bn extra and about 10 years of overtime in the project. (Sakin, 2019, p.105, p.106)

4.3.2. Digital Engineering Review

Once involved key subcontractors into the BIM environment, they have utilized BIM process and strictly obligated to follow the coordinated BIM Model. After producing the BIM Model in LOD350 detail, it is published to the relevant project teams and subcontractors in order them to use the model to create end products.

In all disciplines, 2D shop drawigs are reviewed in accordance with the BIM model. The finished engineered and coordinated BIM Model is the sole reference for the project teams to review end products to deliver site the correct data. If there is any non-conformances with the

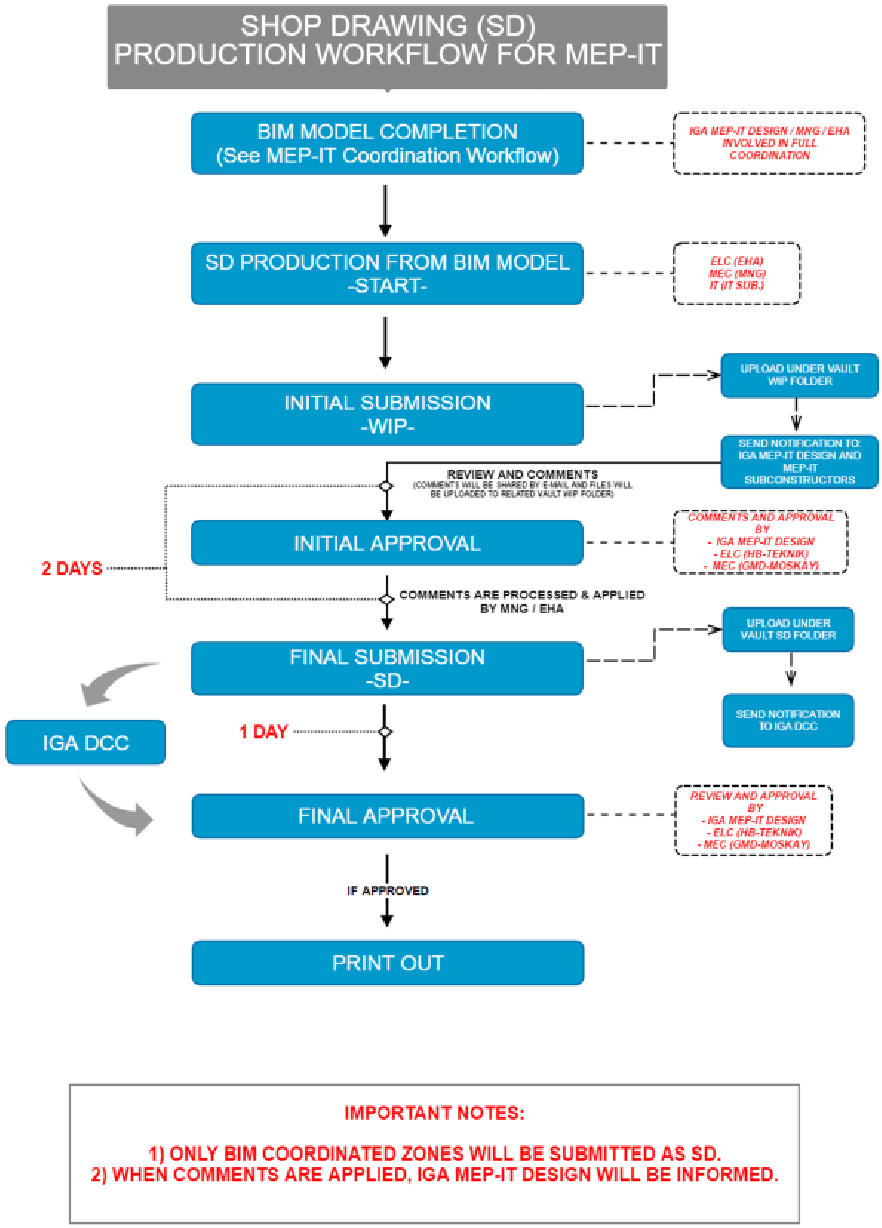


Figure 41: BIM Based SD Production Workflow

model which is done out of the BIM environment, there is probably a corruption and during the digital engineering review process, these corruptions are being cleared.

Above in Figure 41 there is the SD production workflow. Final touches are done with the shop drawing review procedure and remaining issues are cleared caused by non-conformity with the BIM model. This provides a very fast and clear reviewing process where it is a must in such a complex and fast paced construction project. The general SD production worklof for MEP-IT

Shop Drawings is an ongoing procedure in IGA (Figure 42). By the end of this processes, shop drawings are being delivered to site for production. Below is a comment sheet for a mechanical shop drawing submission that is referring to the BIM model.

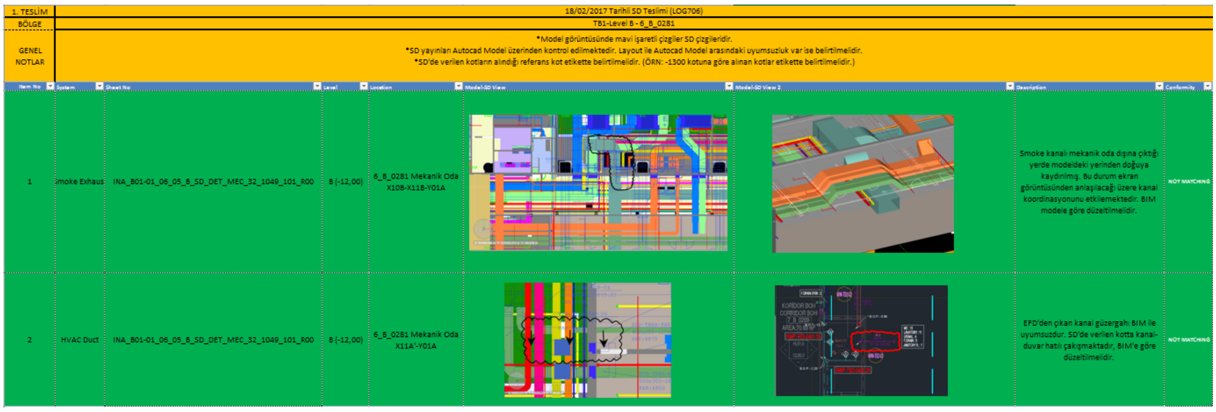


Figure 42: Example Shop Drawing comment sheet based on BIM Model crosscheck

4.4. Construction Management with Mobile BIM Integration

After design coordination and engineering review processes, final product is delivered to site for production. This is a very important and extraordinary process which millions of square meters of BIM Model are delivered step by step, for a fast-paced production on site, multi-disciplinary and fully coordinated. Site delivery is done by 150 iPads on site with BIM integrated softwares. Autodesk products are being used to manage BIM workflows. The aim is to steer site installation progress while making it cost effective and high quality with minimised re-work. All construction processes are managed with dedicated workflows and execution strategy by the BIM team in IGA project.

Project control, quality control and test and commissioning processes are executed on site in a sequence and relation where BIM helps the execution and monitoring of each process to be done smoothly with minimal errors. We can objectify the concept of BIM construction delivery as an engine and a gearbox of an automobile. In this concept which is represented in figure 43, we can then understand better how the concept runs under below statements;

- There is No Reverse Gear: There is no reverse gear since the nature of design to construction delivery based on BIM gives the essential tools to prevent all engineering and design problems before construction starts.
- There is a relation between gears: There is always a relation and interaction between the site engineering which we can also define as the "site project control" and quality

control processes in terms of both jobs done on site and relations between project teams.

- BIM acts as an engine for construction management: BIM is the core of construction delivery processes indicated as 1st, 2nd and 3rd gears in figure 43. With the concept of BIM, project teams are managed in a sense of common understanding where the essential information of projects are shared correctly and on-time to all parties in the project.

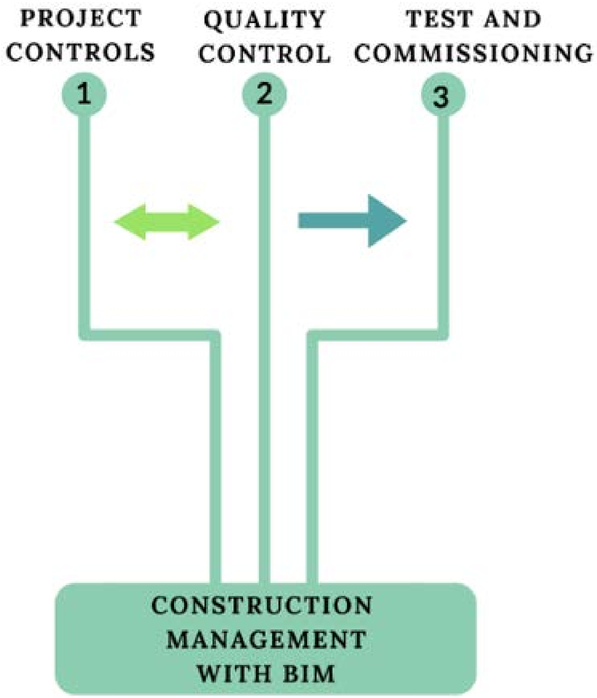


Figure 43: Construction Management with BIM as an Engine for Site Processes

Project control and quality control processes are interoperable in relation with the site installation. The compatibility of the construction works with the BIM model on site was contractually stipulated to the subcontractors in IGA project. Notification for Inspection (NFI) documents as a part of quality control were issued upon completion of an installation on site digitally through mobile tablets on BIM360 platform. Those documents were the final quality control check for site installations and subject to progress payments for the responsible subcontractors. BIM site team continuously monitored and supervised site installations before the final inspections and in case of any non-conformancy of any system whether the installation is ongoing or finished, opens observation records through mobile tablets and registers to the BIM360 platform. Those observation reports are automatically linked with the related NFI documents and are mandatory to be closed by the subcontractor for them to recieve progressive payments. This causes the subcontractor to correct their installations if there are any non-conformancy with the BIM model. This process is crucial for a very complex environment of coordination which multiple disciplines including architectural, structural, mechanical, electrical, ICT and special airport systems such as baggage conveyors involve in a very strict job schedule and sequence of work. After the site installations and quality control process, test and commissioning process starts.

Figure 44 represents an overview for design to construction delivery management process. It is very important for all project processes to be logically dependent to an all inclusive, as engineered and centralized BIM model. This frame can explain where BIM enabled project management is more than having a multi-dimensional model, where there is an overall process in order to get success in project deliverables.

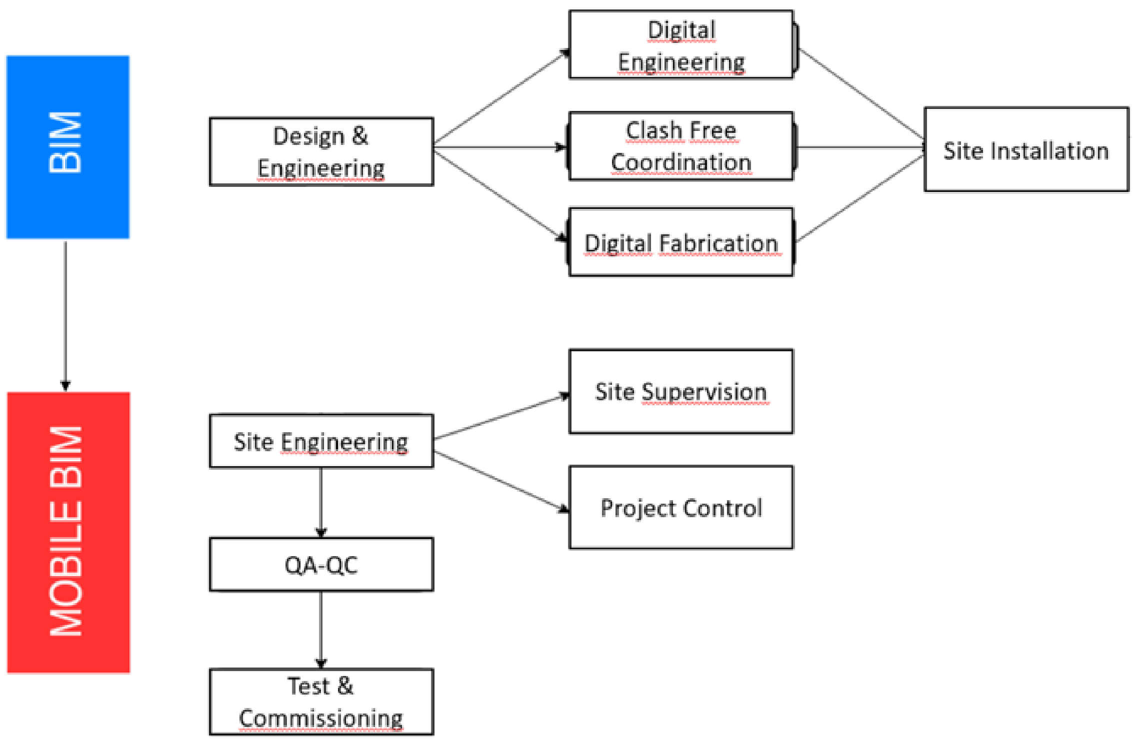


Figure 44: BIM centered design to construction delivery and project management process

BIM360 on iPads are functional on site with the following context;

- Fully coordinated BIM Models,
- All approved 2D shop drawings,
- QA-QC documentation including MAFs (Material Acceptance Form) and Method Statements.

- QA-QC processes; inspection forms, inspection checklists and site observations.

4.4.1. Project Control and Site Engineering

Delivery of fully constructable BIM Models into the site makes site teams conduct installations in the light of clash-free virtual environment of BIM Models. This provides site team the world of correct application in their hand, even before construction has been started.

In the first phases of construction, coordinated BIM Models are approved and published to construction site, before the installation. In Figure 45 it can be seen that 3D shop drawing sheets derived from BIM model were delivered to site before the construction has started. Site teams were fastly involved with 3D shop drawings and changed their conventional mindset and face with digital transformation right next to them. This leads to a huge cultural change and people transformation into a more clear minded and efficient people with collaborative work process.

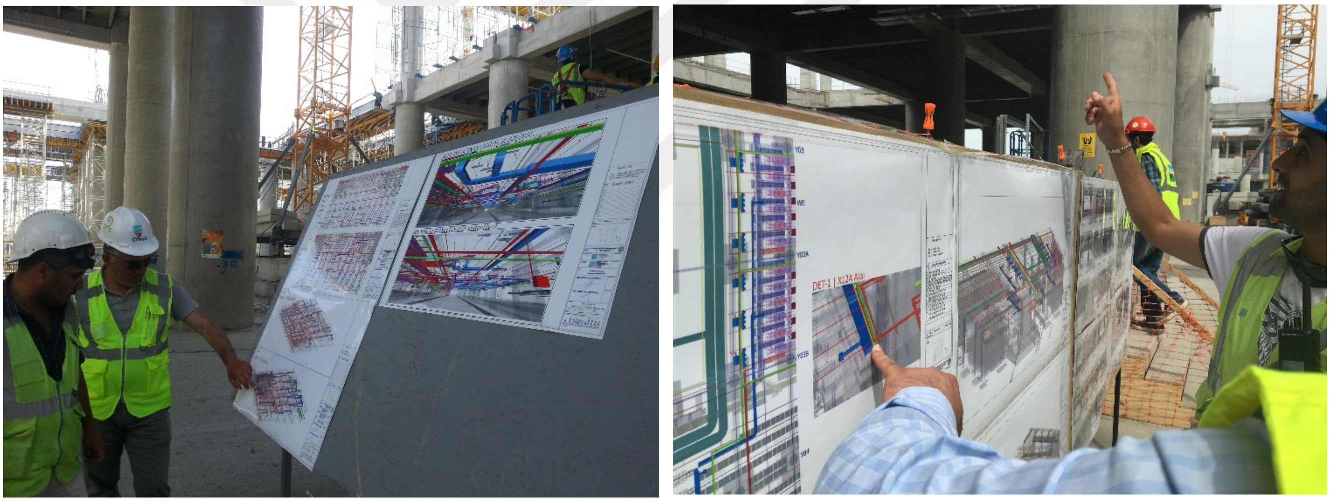


Figure 45: BIM Model outputs on site as hard copies.

Below in Figure 46 is a 3D shop drawing delivered to site, consists of all disciplines and systems allowing first fix site installations including Architectural, Structural, MEP-IT, SAS (Special Airport Systems) elements.

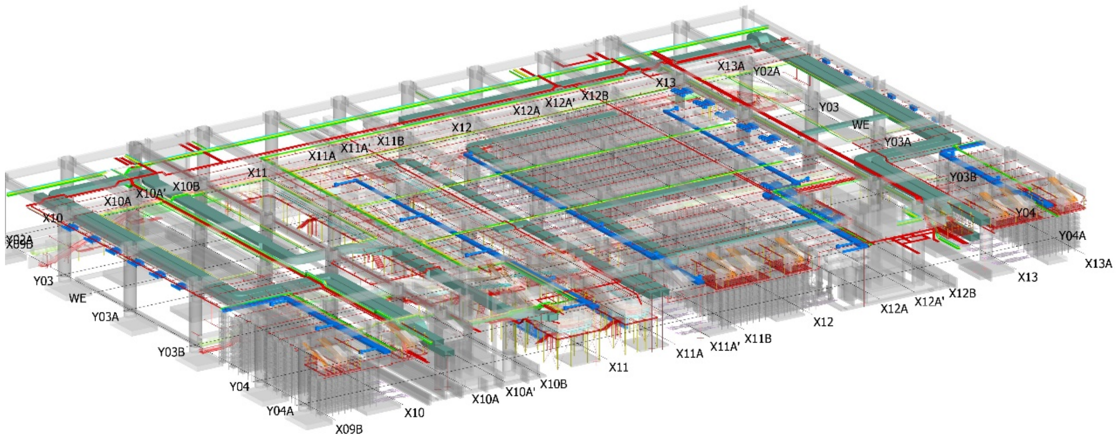


Figure 46: 3D Shop Drawing Delivered to Site

After utilizing 150 iPads to site teams, BIM Models are shared directly to site via BIM360 Field application. The outstanding digital revolution has been developed in the whole project including all disciplines and all project responsibles.

Implementing the mobile BIM into the project is done by training sessions, generated user manuals and continuous support in order to keep project site teams involved and familiarized.

At the time speaking, 150 active iPad users and total of 355 users actively involved in BIM360 environment in order to track the project data including approved 2D shop drawings, QA-QC documentation, site observations and inspections.

Another break through in IGA is utilizing BIM Site Team in order to supervise site installations in compliance with the BIM Model, with the help of mobile tablets and BIM360 applications. BIM site team have been working closely with other discipline site responsibles and even subcontractors leading them to the correct site installation.

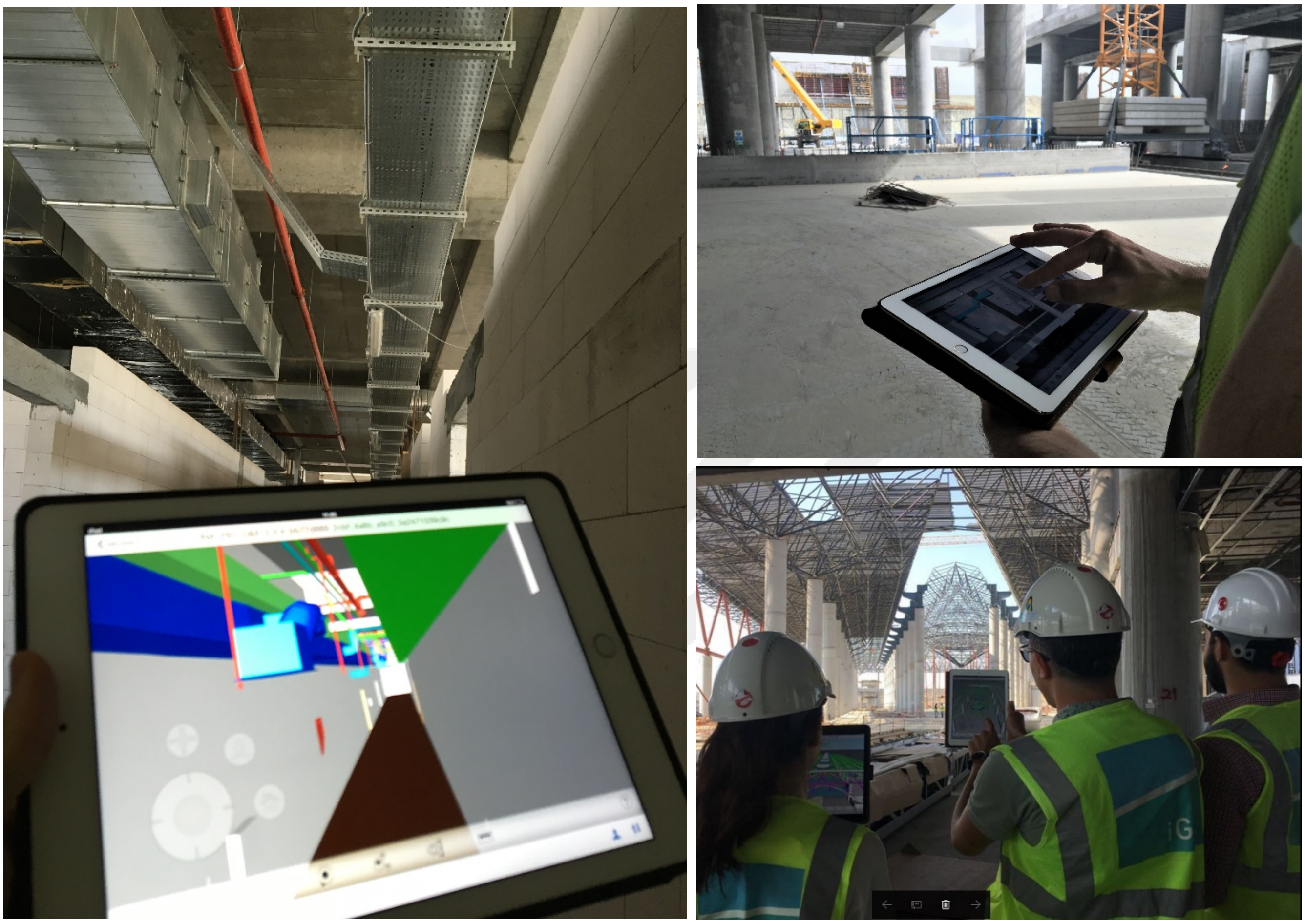


Figure 47: BIM on site with iPads

Via training facilitated by BIM engineers, site engineers and QA / QC staff have been familiarized with the new technologies, job flows and collaboration techniques. The on-site tasks associated with this project included setting up weekly sessions that allowed users to increase their ability to use the framework. With both teams, these workshops are ongoing and frequently used to inform beginners and often keep existing users updated with the services and workflows used. The Mobile BIM Guide was prepared and circulated by the BIM department to give all stakeholders access to project details and to give all parties allocated separate roles to conform with the necessary design and development process. As a result of the Mobile BIM Guidance, site teams achieved mobility in project site execution. Figure 47 and Figure 48 shows photographs from site team using mobile tablets to access BIM and common data environment.

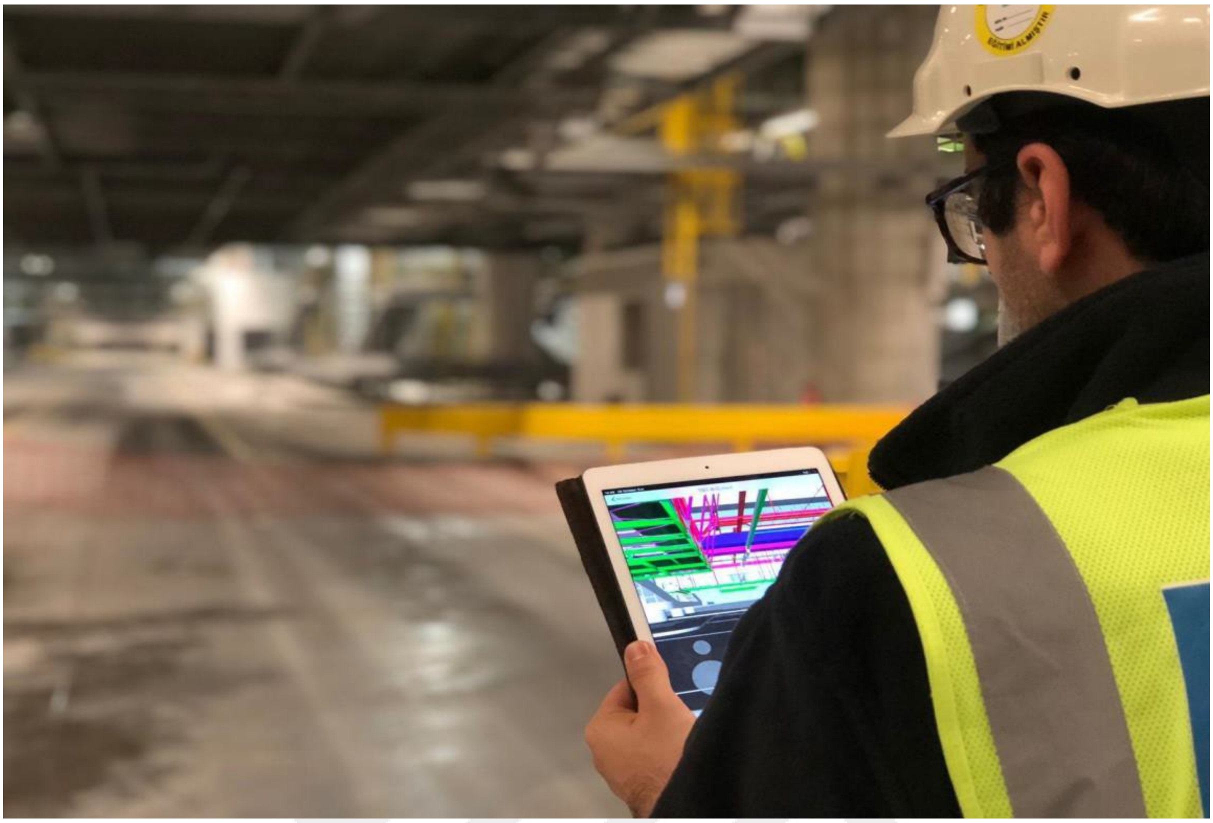


Figure 48: BIM Engineering Team Member on Site

BIM site team make sure that BIM compatible site installation is going on. If there is any non-conformance or lack of coordination, they are creating issues trough BIM360 and assign them to the relevant subcontractor and project responsible with a due date in order them to resolve the issue. Below is an example of site installation of air ducts, electrical cable trays and baggage handling system platforms conforming with BIM model coordination.

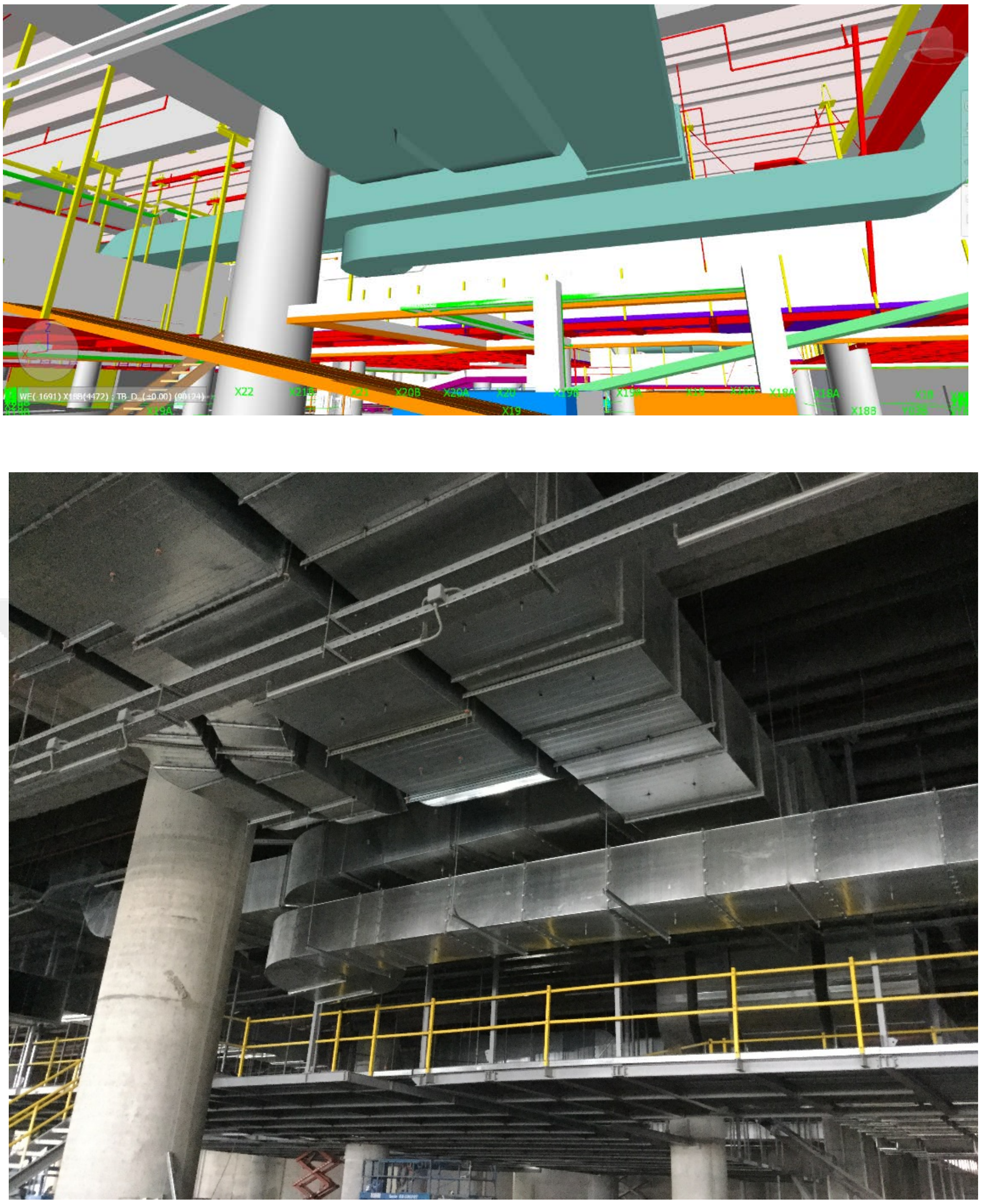


Figure 49: An example of BIM compatible site installation

In Figure 50, there is an example of a site observation created by BIM Site Team, caused by lack of coordination and non-conformance with BIM Model. Project site teams and subcontractors are tracking the observations and giving responses via BIM360 ipad or web applications.

Istanbul Grand Airport	Terminal 0.00 Open ID FY-00025	

Company	IGA	Status	Open
Type	BIM Site Control	Due Date	30 Apr 2017 12:00 AM
Author	Fatih Yöndem (fatih.yondem@igairport.com)	Author's Company	IGA
Date Created	31 Mar 2017 3:54 PM	Root Cause	

Description

BIM Modelle Uyumlu Olmayan HVAC Duct Montajı

Location	Terminal > (0,00) Level D > TB2 > TB2-2
Location Detail	C686/687

Additional Properties for ID FY-00025

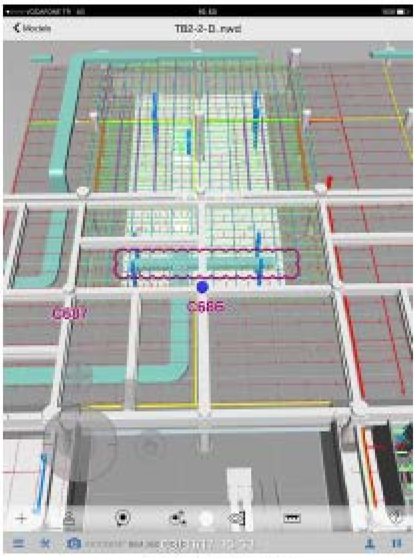
Discipline	Mechanical
BIM Issue	☐

Comments for ID FY-00025

Asim Umut Özbey (asimumut.ozbey@igairport.com) 10 Apr 2017 4:20 PM	08/04/17 tarihinde aksiyon alındı, düzeltilmektedir.
Fatih Yöndem (fatih.yondem@igairport.com) 31 Mar 2017 3:57 PM	BIM modelle uyumlu olmayan kanal montajı yapılmıştır.

Attached Images for ID FY-00025

2017-03-31 15:54:22



2017-03-31 15:53:05

Figure 50: Issue created for non-conformed installation on site with BIM model.

BIM360 layout and compatible robotic total stations are also utilized in the project by BIM Management Team in order to close track the BIM conformity of the site installations.

Leica's total station fully compatible with Autodesk BIM360 Layout is procured and being used precisely. Below is a brief workflow of how BIM model is integrated into the site via robotic total station and Autodesk solutions.

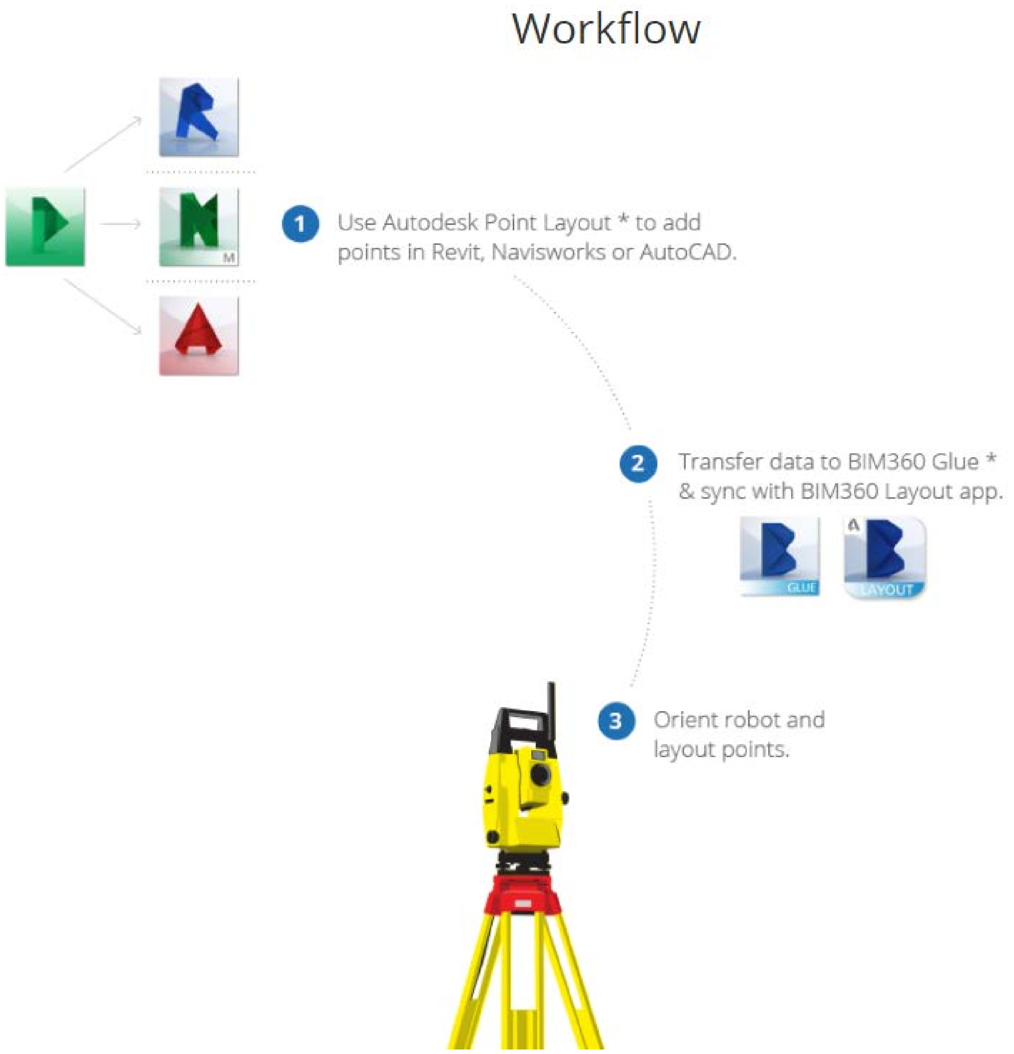


Figure 51: BIM Site Implementation Using Robotics and BIM Software

As seen in Figure 51, points derived from Revit or Navisworks (Revit used in IGA) via Point Layout application and delivered to total station with the help of BIM360 Glue and Layout apps. As a result, coordinated BIM Model brought to the site allowing the site team to precisely control the site installations.

4.4.2. Quality Assurance and Quality Control

Quality assurance of overall project and quality control of production on site are done through BIM workflows, using BIM360 Field software in MEP-IT, SAS (Special Airport Systems), superstructural and infrastructural disciplines. Project site teams with 150 iPads provided and subcontractors are fully integrated into the system. An expansive digital transformation and cultural change is being happened while more people and subcontractors involved in the project and accordingly, BIM.

Construction QC is done by joint inspections on site starting with a notification for inspection (NFI). All NFIs are tracked through BIM360 systems. Inspection checklists are filled by QC and site teams by having the chance to review all the required documents on site via BIM360 on iPads.

iGA	All QA-QC Observation Status Summary						2.06.2017
Company	Draft	Open	Work Completed	Closed	Total Transaction	Past Due	% Complete
Company A	2	254	24	323	605	159	53,4 %
Company B	104	61	2	8	175	14	4,6 %
Company C	0	43	0	17	60	41	28,3 %
Company D	0	20	0	41	61	1	67,2 %
Company F	1	15	2	40	58	8	69,0 %
Company G	0	5	1	22	28	0	78,6 %
Company H	0	5	0	2	8	4	25,0 %
Total for all companies	125	612	30	613	1383	291	44,3 %

Figure 52: QA-QC Observation Statuses (derived from BIM360)

By utilizing BIM QA-QC control mechanism on site;

- Project teams can close track on the issues they are created on site. Hundreds of issues minor and major are under control with given due dates for each of them.

- Easy and precise subcontractor performance follow-up with very detailed reports, easily extracted from the system without any effort, by already populated information on site. One example report can be seen in Figure 52.
- Every single defect on site on track and under control, appropriately documented and reachable data collection is stored on cloud about the construction lead to huge amount of cost and time savings.
- By utilizing BIM on site, inspections can be done by less people overall in the project that leads to cost savings.
- Effective decision making for project executives by the help of high level executive reporting.

  To give an example; it was a former prediction to utilize 50 people on the peak, only for QA-QC team on site in order to carry out all MEP-IT-SAS inspections in construction lifetime. However with utilizing BIM on site, this amount was reduced to only 15 engineers, owing to BIM site integration.

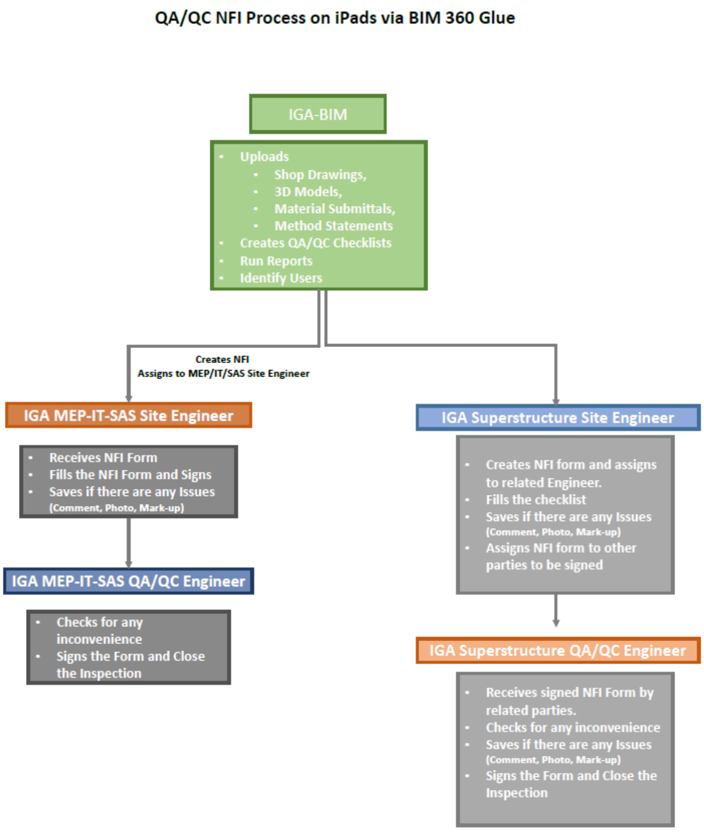


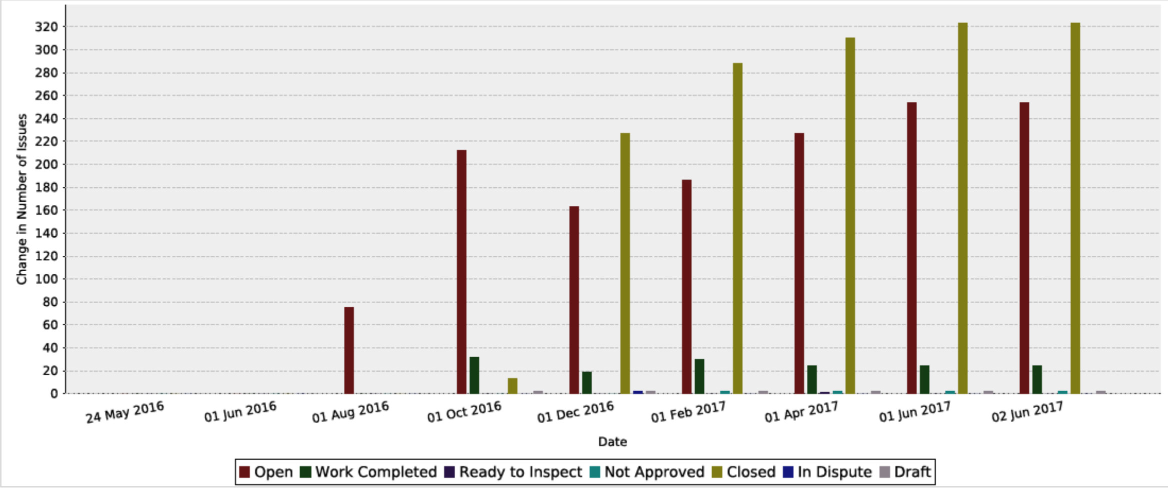
Figure 53: IGA BIM Inspection Workflow for MEP-IT-SAS and Superstructure

Table 8 shows a report derived from BIM360 for one of the subcontractor shows the performance of closing issues.

Table 8: Issue status change table for a subcontractor

Istanbul Grand Airport | Company A_Observation Status Changes

Date range: All



Date	Open	Work Completed	Ready to Inspect	Not Approved	Closed	In Dispute	Draft
24 May 2016	0	0	0	0	0	0	0
01 Jun 2016	0	0	0	0	0	0	0
01 Aug 2016	75	0	0	0	0	0	0
01 Oct 2016	212	32	0	0	13	0	2
01 Dec 2016	163	19	0	0	227	2	2
01 Feb 2017	186	30	0	2	288	0	2
01 Apr 2017	227	24	1	2	310	0	2
01 Jun 2017	254	24	0	2	323	0	2
02 Jun 2017	254	24	0	2	323	0	2

Report run on 02 Jun 2017 7:01 AM by Ahmet Ekrem Çelikel (ahmet.celikel@igairport.com) Page 1 of 1

4.4.3. Test & Commissioning

Testing & commissioning is considered to be one of the vital stages in construction sector since it is the *Final* physical work done at any project site. Test & commissioning stage in IGA project can be defined in three main phases;

- Developlment of commissioning model
- Digital test&commissioning of equipments
- Commissioning to operations information delivery

Above 3 phases are planned, executed and finalized with BIM in 18 months prior to the day one of operations.

To give an example for testing & commissioning of an HVAC unit, it include the following steps;

- Making sure that all equipment’s apply their designated functional scenario when it comes to cooling, heating and ventilation.
- Ensuring the equipment’s run smoothly, not noisy, reliable and above all runs safely.
- Applying the worst case scenario simulating a *Fire condition* where very strict test procedure will be carried out while applying International Fire Codes (i.e. NFPA).

The steps above will be documented in special testing & commissioning sheets filled by professional engineers. The inspection sheets & reports shall be all kept in special *Archives*. The project archive shall house the entire history of each and every individual unit (i.e. Material Technical Submittals, Approvals, Charts, Data collected, Site Installation & Inspection Reports, testing & commissioning sheets and above all *Fire Mode* scenario). This will all be utilized by BIM360 system integration on site with iPads.

To illustrate the above procedure, a wall mounted break-glass and push-button fire alarm device will be activated *simulating* fire condition. By clicking on the device, a menu will pop-up presenting the entire details of this highlighted device enabling user a *direct access* to the archives. An actual fire alarm buzzer will loudly sound ordering an immediate evacuation, fire strobe will flash continually and the nearest CCTV camera shall automatically point towards the exact fire location. The fire condition remains active till the fire alarm is *acknowledged & re-set* at the main fire alarm control panel.

All the process from the documentation to site inspections are held by BIM360 platform with delivering TCR (test&commissioning request) and relevant attachments including checklists directly on site.

Finally, this shows how BIM can *merge* the entire diverse airport systems into a user *friendly menu* enabling the user to access both history & future of existing systems. Thus BIM can save us time, money, effort and offer very interactive approach to the airport facilities.

4.4.4. Progressive Reporting and Monitoring

Continuous monitoring of the work performed in the field and evaluation of the performance of the subcontractors were realized through periodic reports received from the BIM platform. BIM has a very crucial role on integrating, monitoring and management of more than 60 subcontrators that are registered on BIM360 platform. Enabling subcontractors on the other end of BIM360 platform gave the BIM Team to deliver and achieve KPIs and track performances of subcontractors with progressive reporting. BIM360 provides automatic report generation with pre-set options on a timely basis, which helps saving a tremendous amount of time where normally a team of people would conventionally be dedicated for this task. Automatically generated reports include issues, quality control inspections, digital checklists, progress monitoring activities and test & commissioning. BIM360 platform also facilitate adaptation of subcontractors to BIM where it becomes a daily activity to track contruction activities digitally for key engineers registered to the platform.

BIM360 Dashboard for IGA project can be seen in Figure 54. This dashboard is customizable on user basis with various widgets including issue tracking, company performance indicators and statistical data for construction progress.

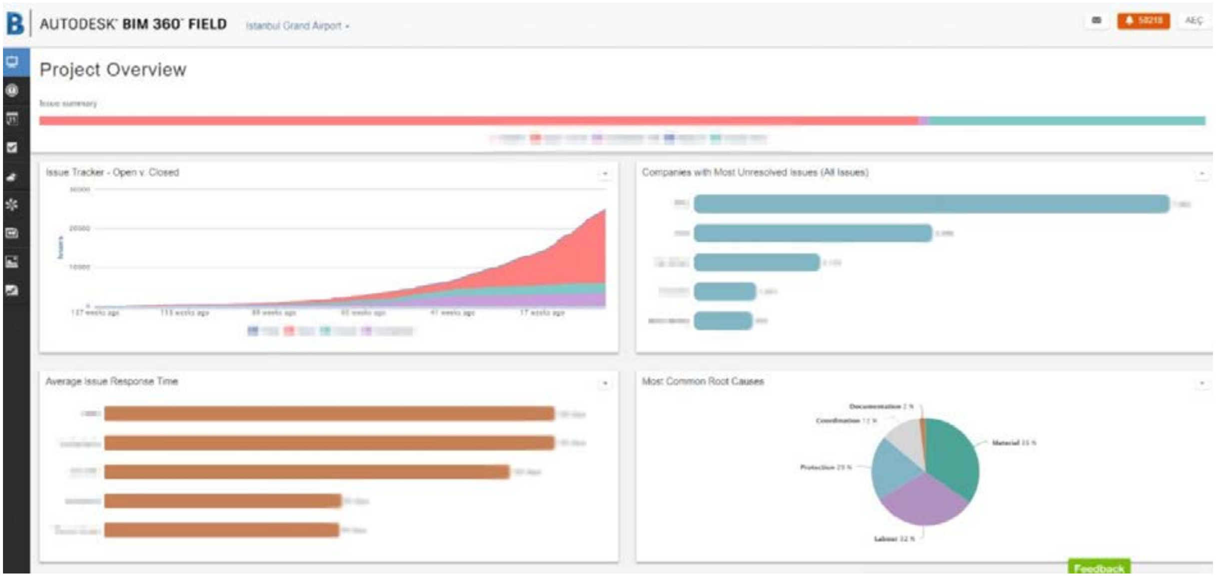


Figure 54: BIM360 Dashboard View for IGA Project

4.5. 4D/5D BIM: Scheduling and Cost Control

Entire planned activities are integrated within 3D BIM Model of IGA to simulate construction project from start to the end. It has acted as an analysis tool for executives to help them take critical decisions on preventive and corrective actions to avoid unpredicted delays. We can summarize the usage of 4D BIM model in IGA project as smart linking of 3D model with project schedule, construction project visualization, review capability of planned versus actual activities on site, tracking and monitoring project progress and critical decision making for executives.

Especially for the executive decision making, 4D snapshots of key assets and zones are being shared weekly with directors and responsibles. In Figure 55 below, there are samples of 4D snapshots derived right from the shared presentations.

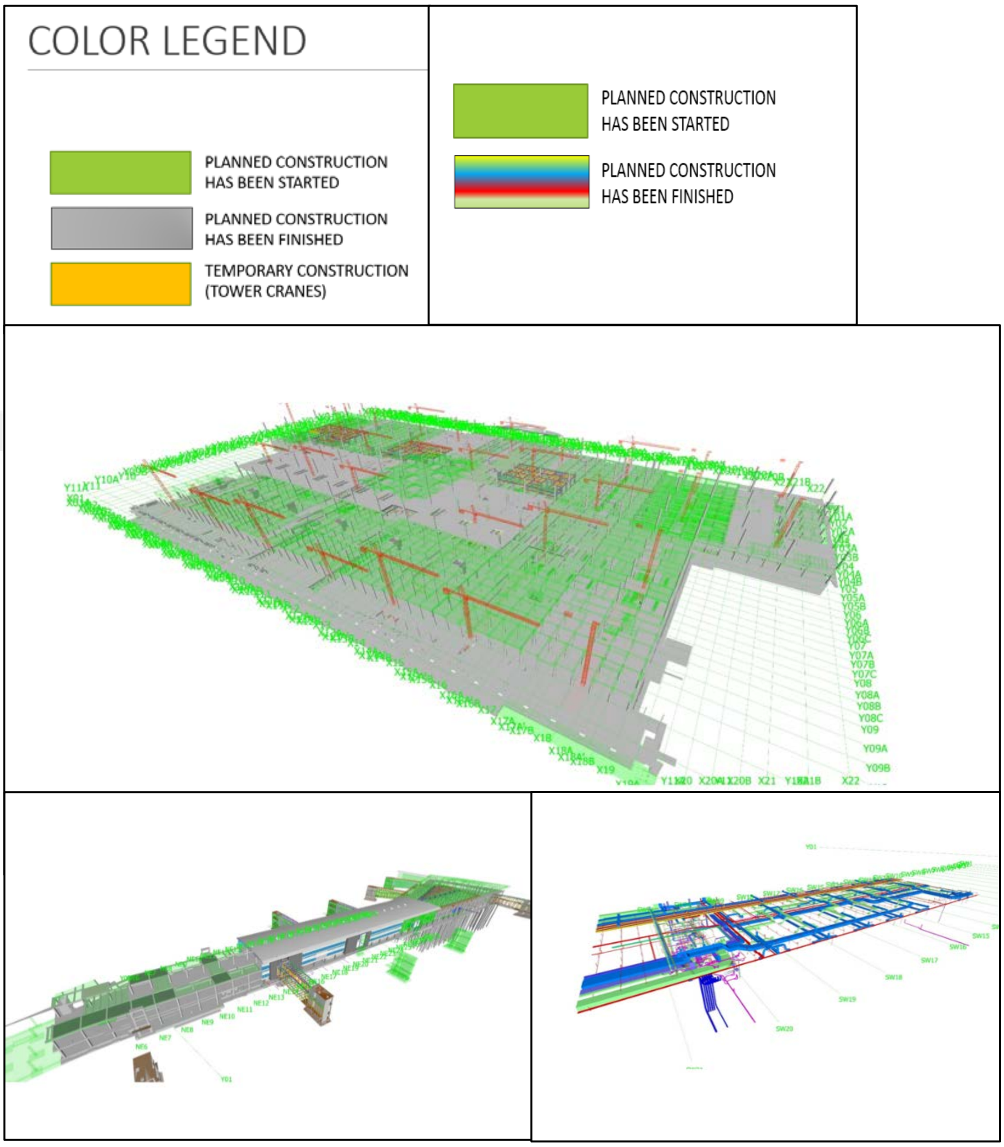


Figure 55: Terminal and Piers Sample 4D Model with Color Legend

The main advantage of using BIM for quantity take offs is to creating actual quantity reports including coordinated and near as-built calculations of items. Bill of Quantities (BoQ's) from the model are generated and issued to the technical offices of each discipline. In Figure 56, the workflow of 4D/5D integration with site progress reporting can be seen. As can ve seen from the workflow, in terms of 5D, detailed quantities are issued to the technical offices of each related department and being used for overall progress of the project zone by zone and level by level. Additionally, the BIM BoQ is being used for const control for subcontractor payments and project progress in terms of costs.

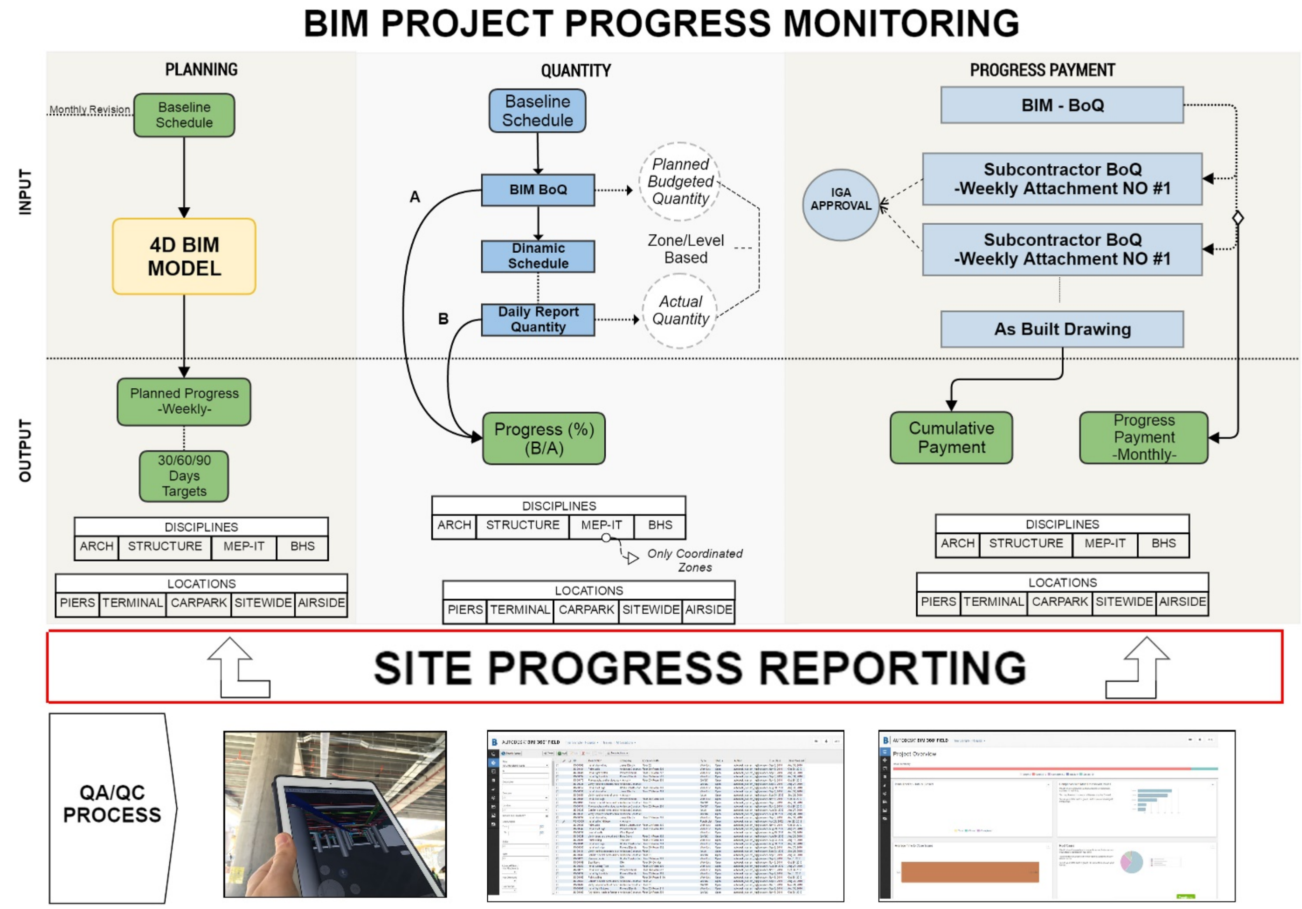


Figure 56: BIM Project Progress Monitoring Workflow

4.6. Facility Management

Facility Management (FM) is the stage after the project delivery and handover. Full BIM implementation into the project is crucially important for FM and operations. All the collected and generated data will be handed over when the project is finalized. In such a complex project, the big data is easily handled thanks to innovative BIM processes. The data consist of graphical and non-graphical information. As the graphical information, complete BIM Model will be handing over with extraordinary amount of information bonded, 2D graphical documents about equipments and all other systems. Non-graphical data consist of all documents about QA-QC site inspections, material approval forms, inspection sheets, test & comissioning reports, checklists, equipment data with all necessary documentation linked and much more.

4.6.1. Digital Twins and Airport Operations

When it comes to the operations and maintenance, BIM will be there also. With all the information in hand, with the help of visualised environment and mobile applications, all system will be integrated with each other and controlled over a dashboard with mobile application support.

Many of the asset records, such as information about access plans and work schedules, a list of pending activities and descriptions of historical asset failure data, triggers and effects, may be the basis of a Computer Aided Facilities Management (CAFM) system used by a facility management contractor. Many of the information given by a construction project, such as technical data, design specifications, operational instructions and fault finding instructions, will also be provided to the CAFM system (Manning, BIM Task Group, 2014). In Figure 57, sample screenshots of a demo model exclusively prepared for IGA facility management operations can be seen.

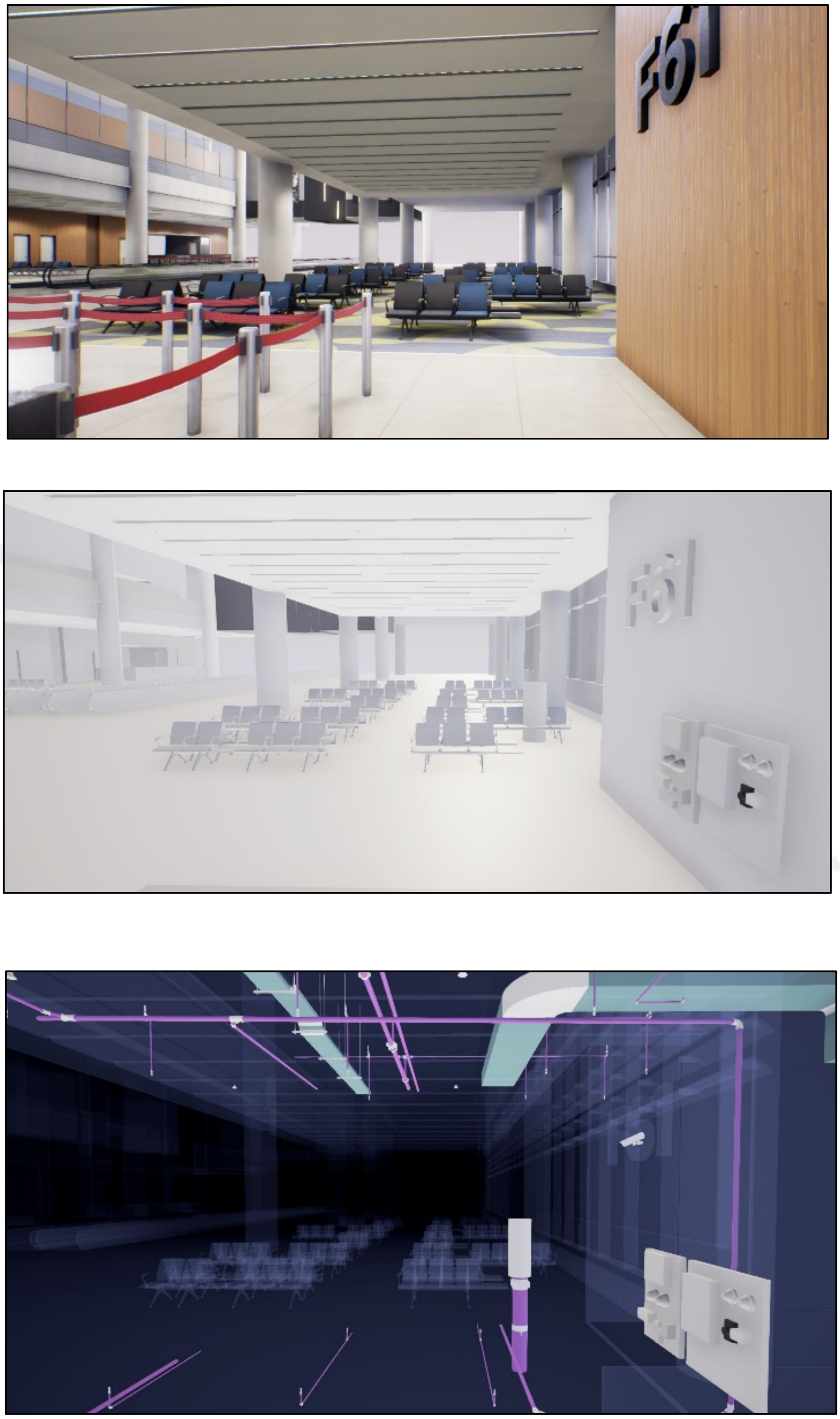


Figure 57: Facility Management Linked Model

The processes that can be integrated in BIM-centered facility management are generally described below

Asset Management - depreciation, equipment, furniture, telecommunications, wiring

● Strategic Planning - Real Estate, Business, Inventory, Field Use Projections

● Facilities Planning and Management - Appointment, Resources, Features

● User Management and User Journeys - Users, Tenants, Staff

● Maintenance Management - Maintenance requests, Scheduled / preventive maintenance, Alarms

● Emergency Management - Disaster Plan, Security Information

● Portfolio Management - Construction / Alteration, Moving

● Lease Management - Financial information of immovables

● Asset Management - Equipment, Hardware, IT systems, Infrastructure (cable, etc.)

● Energy Management - Certificates, Cost, Renewal

● Short / Medium / Long Term Facility Plan and Financing

Facility Management application that provides a wide range of capabilities with IoT integration. In Figure 58, a demo dashboard of real-time BIM model intagrated Facility Management Dashboard can be seen.

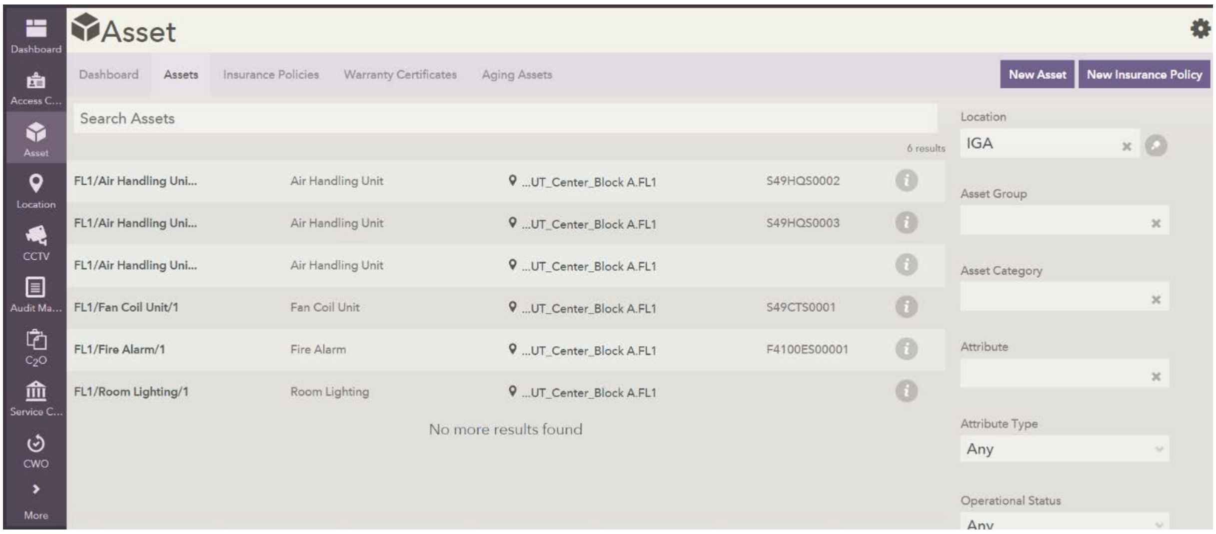


Figure 58: Facility Management Dashboard

4.7. Energy Analysis

It is a common sense that conducting decision making process to provide sustainable features for the structure should be in design and preconstruction phases. However, in the literature there are studies asserting that optimized solutions for retrofitting existing buildings are more beneficial in terms of cost and time than constructing a "green building". Having said this, since BIM provides us many opportunities to use specific tools for energy analyses, sustainability analysis has been conducted for BIM Models of Istanbul Airport Project to have an overall idea on energy consumption of the project and optimized solution alternatives for retrofitting. This process could accelerate Envision certification process and save relatively a significant time required for such analysis by using conventional methods. (BIM Department of IGA, 2017)

According to World Green Building Council's 2015/2016 annual report, buildings account for over 30% of CO_2 emissions and they use about 14% of the world's drinking water. Considering this fact and rising demand for sustainable buildings due to increase in cost of energy and environmental concerns, sustainability analysis holds utmost importance.
Accordingly, having been the world's largest airport project, İstanbul Airport Project includes a Terminal Building of 950.000 m2 and Pier Buildings of 320.000 m2 that require an efficient energy analysis. Hence, BIM implementation provides opportunities in terms of accessing all project data including 3D models, drawings, project documents, technical asset data and so on from a single digital platform while allowing facility managers a fast modification or update possibility on data whenever needed while eliminating great waste of time and cost. As a result, following items can be given as benefits of BIM for sustainability;

- Energy modelling (detailed energy analysis of the building for renewable energy options such as solar energy)
- Building orientation (providing best building orientation option that leads to minimum energy cost)
- Reducing waste of time and cost for energy analysis (ability to change and test various design parameters)
- Access to current data about energy costs and weather

The following software has been used for sustainability analysis of terminal building.

Green Building Studio (GBS): This is a web-based energy monitoring service that helps consumers early in the planning process to determine the environmental effect of specific building components. Analysis capability of this program includes energy and thermal analysis, analysis of lighting and shading and analysis of value/cost. Energy/thermal research assesses the consumption of energy, greenhouse dioxide, ventilation and airflow. The value and cost functions determine lifecycle evaluations and lifecycle costs.

Insight 360: Current workflows including Revit Energy Analysis and Lighting Analysis for Revit are implemented by Insight 360. In addition to understanding PV energy efficiency and saving and evaluating design scenarios to track performance spanning the building lifecycle, and assessing performance against Architecture 2030 and ASHRAE 90.1 benchmarks, it facilitates simulation of solar radiation on mass or building element surfaces with new solar analysis workflows.

Autodesk Revit 2017: Green Building Studio and Insight have interface with Revit 2017. For analysis, 3D models are processed through Revit 2017 application.

In total, 5 different models were taken under consideration which is quite an outstanding number for such a big-scale project with Terminal Building of 950.000 m2 and Pier Buildings of 320.000 m2. In Figure 59, you can find a screenshot taken from Revit 2016 showing a holistic view of Terminal and Pier Building Models altogether. Furthermore, the combined model given below is at its real World coordinates having high accuracy in level and shape details in terms of architecture and structure to achieve accuracy in total volume of energy analytical model created automatically by Generate command (in Revit 2017) or Generate Insight command (Revit 2016) in Analyze section in ribbon.

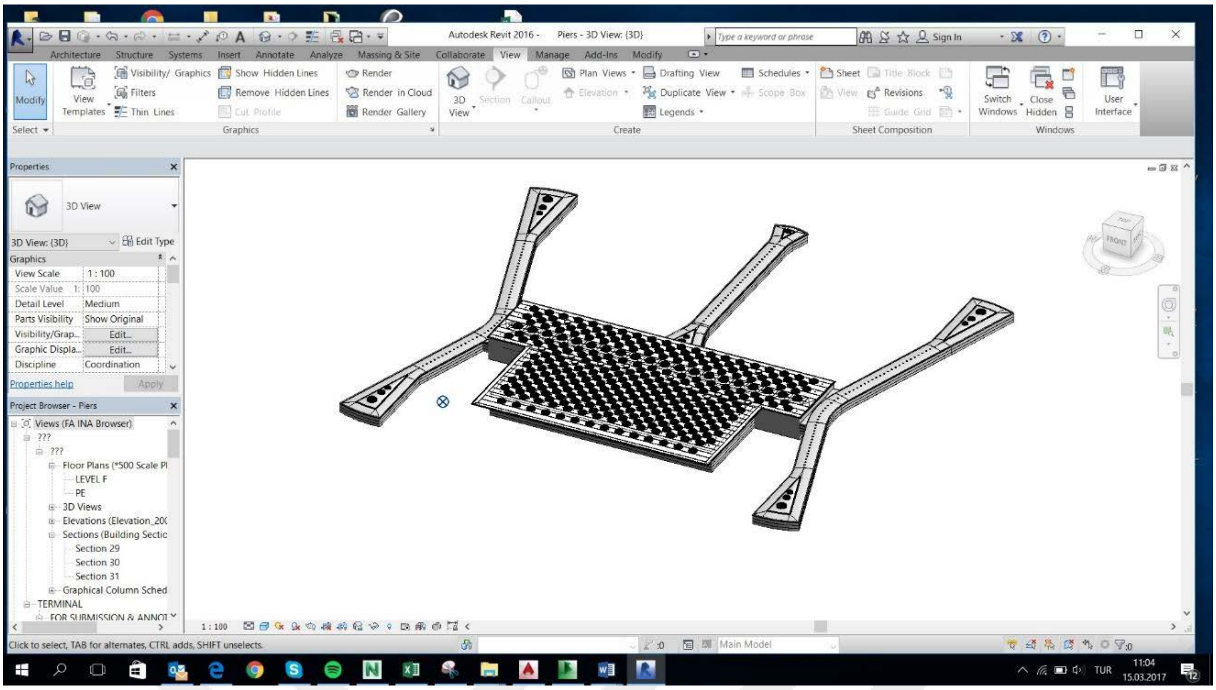


Figure 59: Combined Architectural and Structural Model of Terminal & Piers

Having said these, whole model is divided into 5 sub-models -in accordance with the zoning plan as follows:

- Terminal 1 (all levels)
- Terminal 2 + Terminal 3 (all levels)
- Pier 1- Pier 2 (all levels)
- Pier 3-Pier 4 (all levels)
- Pier 5(all levels)

With a proper optimization and project assumptions, we have succeeded to analyze all Terminal and Pier Buildings and found annual and monthly data –both in energy and 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 the project teams to foresee future energy consumption of airport buildings. Having considered this, sample outputs taken from GBS dashboard are given in Figure 60 and 61;

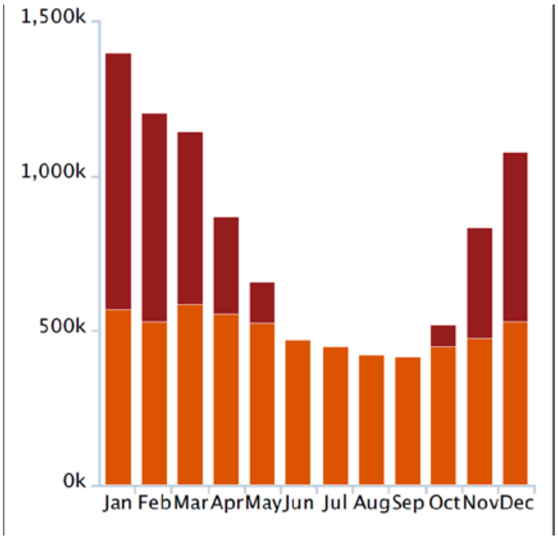


Figure 610: Energy Cost in Energy Units

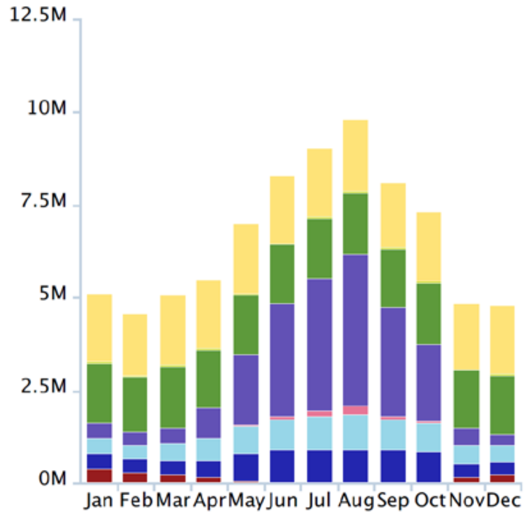


Figure 601: Energy Cost in Monetary Units

Lastly, solar analysis sample results of Istanbul Airport Pier1 and Pier Building can be seen in Figure 62.

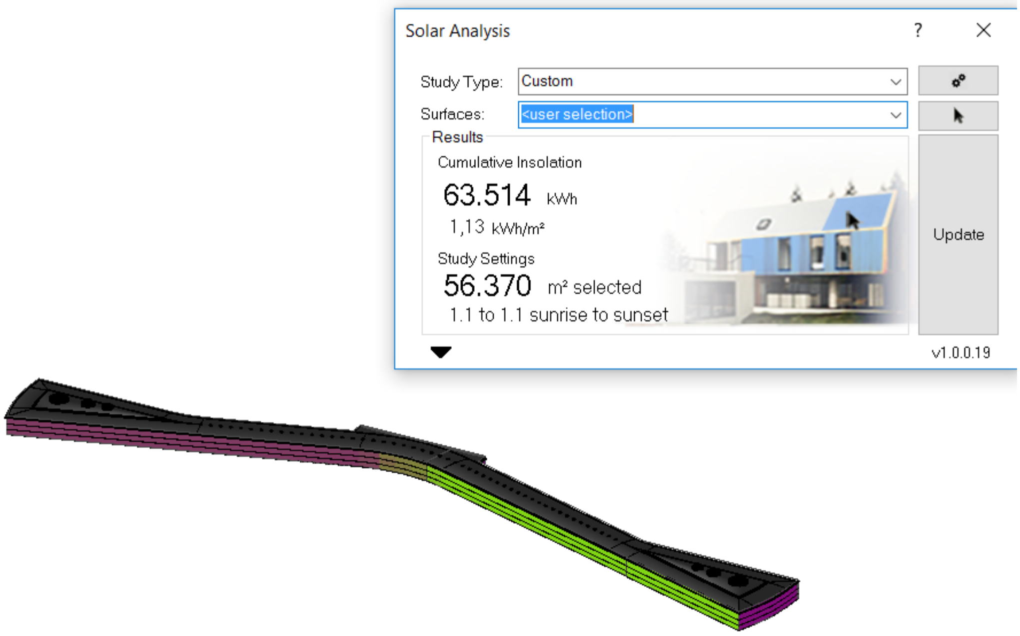


Figure 62: PB1-PB2 Solar Analysis Result

Furthermore, the iterative data we get from the energy analysis process will lead us to take retrofitting decisions in the design of the airport. For instance, solar analysis provides us to acknowledge the photovoltaic energy production we can potentially get via necessary design adjustments in near future.

5. FRAMEWORK DEVELOPMENT

Wide-ranging literature review, a success case study and direct observational investigation in this research results with a framework development that includes a project guideline and consolidated success factors for successful BIM implementation. As given in previous chapters, overcoming BIM barriers and implementing BIM efficiently to a construction project is possible, if effective management done through the lifecycle of project.

5.1. BIM Implementation Guidance for Construction Projects

BIM processes are summarized and visualized in Figure 63. BIM Implementation starts from the very beginning of the project lifecycle, continue until project handover and even to operations phase of the project. However since this research focuses on the construction project lifecycle, operations phase is not included into the roadmap.

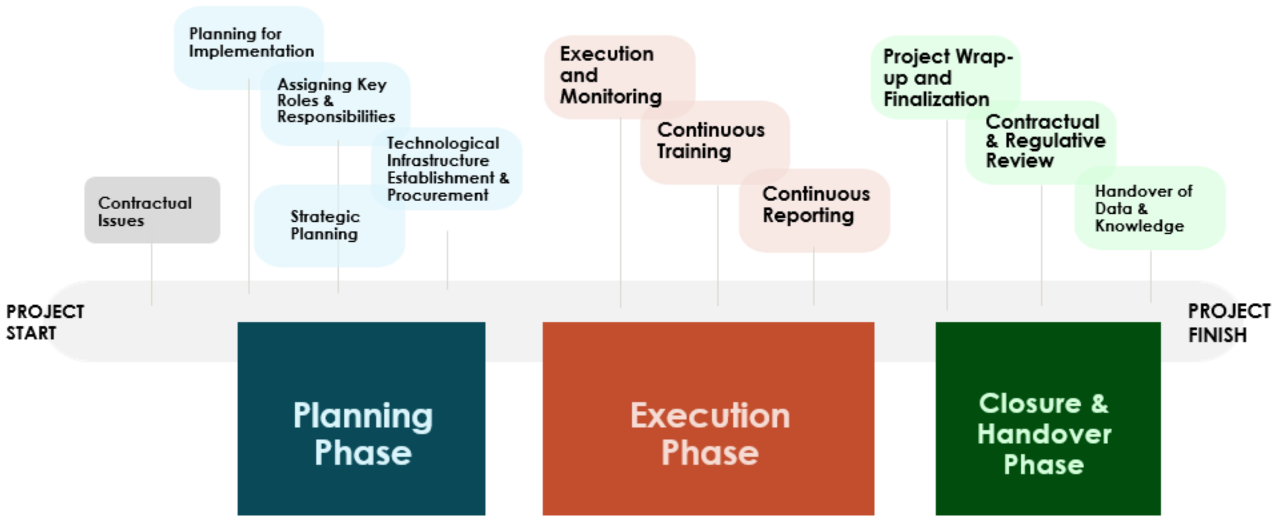


Figure 63: BIM Guide for complex construction projects: a roadmap

BIM processes are detailed in activity / subject breakdown in Table 9. One important aspect is to consider is not to make BIM processes too complex since it is already complicated to implement a whole new approach into a project in nature. Thinking simple but strategic is the key for successful BIM implementation, of course with the right resources, cultural change, management support and enough training.

Table 9: BIM Process Details

Process	Activity / Subject
Planning for Implementation	BEP Preperation Cloud Collaboration / CDE Setup BIM Procedures
Assigning Key Roles and Responsibles	Forming the effective teams for efficient BIM management Positioning of key people to technical departments
Technological Infrastructure Establishment & Procurement	Defining hardware requirements and procurement Defining software requirements and procurement BIM Room facilitation
Strategic Planning	Integration methodology between parties Preperation of dedicated workflows Preperation of continuous training program
Execution and Monitoring	BIM model creation Mobile BIM Organisational and continuous coordination meetings
Continuous Reporting on Technical and Executive Levels	Automatic report generation Site Engineering, Project Control, QA/QC, Test & Commissionin Digitalized Reports
Project wrap-up and Finalization	Documentation and archiving BIM Model Handover BIM Model Integration for Operations
Contractual and Regulative Review for Project Closure	Requirements of employer and validation of approval from next phase building operator

5.2. BIM Project Success Factors

Facing various barriers while managing a BIM based project is very likely. In the new era of digitalization, mobility and smart everything, it would not be so difficult to achieve success where we can measure, monitor and manage every aspect of a project. Consequent to conducting a wide range literature review, gaining experience and investigating a successful case, four success factors can be rooted to BIM project success. Those factors can be listed as People, Process, Technology and Rules. In Figure 64, there is a representation of the success factors together with their subjects.

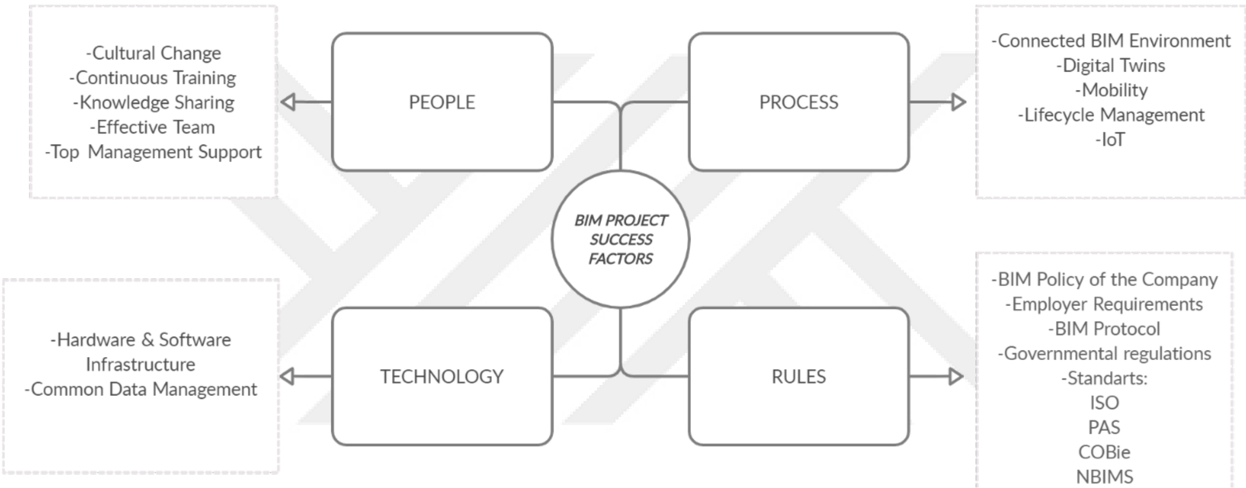


Figure 64: BIM Project Success Factors

Another interrelated difficulty is discussed with the challenge of BIM still bringing a new way of operating that not all interested actors recognize, or are able to accept: the lack of innovative space due to a heavy emphasis on the film. (Jacobsson and Merschbrock, 2017).

6. DISCUSSION AND FINDINGS

In this chapter, resulting positive impacts of implementing BIM, especially in a large scale project are presented. Also the research questions are answered accordingly.

6.1. Positive Impacts of Implementing Mobile BIM in a Large Scale Construction Project

Below is the key positive impacts of the BIM implementation in a large complex project;

- Having authority and control over subcontractor with correct information flow and tracking capabilities.

- Effective communication among all project responsibles including designers, subcontractors, consultants and any other external interfaces and ability to connect people where ever they are.
- Ability to avoid claims issued by subcontractors with accessible information and true design and construction guidance throughout the project.
- Avoiding any unexpected cost overruns and reducing waste on site as cost, time and quality have an utmost importance fort he project success.
- Easier and powerful executive decision making with the help of tools BIM provides including 4D simulation and information tracking capabilities.
- Improving the understanding capability of the complex construction processes and reducing associated risks involved.
- Providing project individuals a complete collaborative environment that allows innovative solutions to be identified, developed and validated in a fast manner.
- Competency over planning and application in asset operation maximising the value during the lifcycle of the asset
- Improved predictability of building energy and environmental performance and operations.
- Increased control on construction with efficient validation of true installation on site compatible with clash-free design that is engineered in BIM environment.

Positive impact on AEC-FM sector especially in Turkish construction industry that enables digital transformation involves economical and social development.

Cultural change of mindsets where old-fashioned conventional methods are innovatively transformed into a form of an optimum mechanism of project delivery and management.

Impact of BIM on time, cost and quality for a project are also briefly explained below;

It is observed that both in academical researches and the case study of IGA, BIM has a crucial role on time management of a construction project, providing lean construction methodology with precise information delivery at every stage of a project.

BIM has a positive impact on reducing costs both in delivery and operation of a construction project. Eliminating rework, one time installation provides cost efficiency. As mentioned in the case study, BIM implementation leads to efficient people management that proves a project can be delivered with less people with correct tools of BIM are applied successfully.

In both design and construction phases of a project, all the processes are closely tracked, documented, managed and delivered with efficiently solving problems in a collaborative environment. That leads to high quality clash-free design, trackable construction in every aspect and reachable high quality and rich information during the operational phase.

As given in the thesis, there is an obvious benefit on time and cost savings only by solving digital clashes before it is delivered to site, fully engineered BIM model is effectively and efficiently affects overall project gains.

7. CONCLUSION

This research aims to provide a guideline for successful BIM implementation in large scale construction projects, where almost every aspect of BIM is beneficial. BIM is a methodology of managing all the lifecycle phases of a construction project and a building, including planning, design and engineering, construction and facility management. It is a combination of project, construction, cost and asset management where all the project information is gathered, efficiently procesessed and distributed to the relevant parties.

Academical researches and industry practises clearly show that BIM has a crucial role on improving the project delivery in terms of time and cost efficiency and quality for design, engineering, construction and operations phases of a building. BIM is estimated to be able to remove unbudgeted improvements by 40% and minimize the time to complete a project by 7% and the time to deliver a cost estimate by up to 80% (Azhar, 2011).

BIM is still being developed in most aspects while increasingly implemented in construction projects worldwide, with a complex know-how. Countries such as United States and United Kingdom have already been adopted BIM as they are developing the methodology and contributing the term countrywise. Realization of targets for time, cost and quality of projects show that BIM is going to be irreplaceable in the future world, in which environmental and economical efficiencies are the key factors affecting the civilization.

In Turkey, familiarization and adoption of BIM as a core methodology in construction projects has been increasing as Istanbul Airport (IGA) has become the center of transformation of conventional methods and mindsets involving numerous subcontractors, designers and project individuals in the BIM envieronment. IGA has also been the leader for cultural change, digital transformation and revolution of human mindset in business manner positively improving creative and forward thinking.

The research objectives were set out as the following:

- To emphasize and activate the important role of BIM, and the potentials of eliminating the barriers in front of BIM implementation in the large scale projects with strategies by technological and organisational aspects.
- To examine uses and purposes of BIM and its role towards a more efficient and effective management of project phases of buildings
- To verify that BIM has positive effects on successful project delivery if it is efficiently implemented into a construction project lifecycle
- To investigate how BIM is successfully implemented into the project lifecycle of Istanbul Airport with a case study
- To establish a BIM implementation guidance by addressing challenges and success factors towards successful BIM implementation in large scale projects

This research has achieved the objectives that were defined. First objective is met by showcasing the benefits of BIM implementation into a large scale project, defining the barriers and indicating how to achieve such barriers in order for successfully benefit from BIM processes.

Second objective is achieved by examining how BIM processes can be integrated into the construction project lifecycle by identifying processes, activities and subjects of BIM.

Third objective was about the verification of BIM that it was obvious from various academical researches and Istanbul Airport case study. When correctly implemented into the project lifecycle, BIM positively effective on cost, time and quality aspects of a construction project.

Fourth objective is achieved by conducting an in-depth investigation on the implementation process of BIM in Istanbul Airport, from design, engineering, construction to the airport facility operations.

Fifth objective was achieved by developing a BIM implementation guideline by addressing BIM processes, together with the success factors including four critical title; people, process, technology and rules.

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