PROJECT PLANNING AND MANAGEMENT USING BUILDING INFORMATION MODELING (BIM)

A Thesis Submitted to
the Graduate School of Engineering and Sciences of
İzmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Civil Engineering

by
Ruti Ruth POLİTİ

December 2018
İZMİR

We approve the thesis of **Ruti Ruth POLİTİ**

Examining Committee Members:

_____
Assoc. Prof. Dr. Engin AKTAŞ
Department of Civil Engineering, İzmir Institute of Technology

_____
Assoc. Prof. Dr. Mustafa Emre İLAL
Department of Architecture, İzmir Institute of Technology

_____
Prof. Dr. Gökmen TAYFUR
Department of Civil Engineering, İzmir Institute of Technology

_____
Prof. Dr. H. Murat GÜNAYDIN
Department of Architecture, Istanbul Technical University

_____
Assoc. Prof. Dr. Nurhan ECEMİŞ
Department of Civil Engineering, İzmir Institute of Technology

21 December 2018

_____   _____
Assoc. Prof. Dr. Engin AKTAŞ   **Assoc. Prof. Dr. M. Emre İLAL**
Supervisor   Co-Supervisor
Department of Civil Engineering   Department of Architecture
İzmir Institute of Technology   İzmir Institute of Technology

_____   _____
Prof. Dr. Şebnem ELÇİ   **Prof. Dr. Aysun SOFUOĞLU**
Head of the Department of Civil   Dean of the Graduate School of
Engineering   Engineering and Sciences

ACKNOWLEDGMENTS

ABSTRACT

PROJECT PLANNING AND MANAGEMENT USING BUILDING INFORMATION MODELING (BIM)

Today, in construction practice, implementation of effective construction management techniques and tools is becoming essential, especially as the scale of the projects increases. Large scale projects pose a challenge to industry; as the number of tasks, parameters and constraints to be considered rises, interaction of these tasks and parameters increases the complexity, as well. While the search for techniques and tools for better coping with complexity will never end, Building Information Modeling (BIM) has recently emerged as an approach that achieves considerable improvement in efficiently handling complexity.

BIM is able to provide a digital visualization of a building or structure in 3D. The necessary geometric data is modeled but more importantly all semantic data associated with the project (function of the element, material properties, construction details, schedules, etc.) is stored with the model. The intent is to have a single model of the project for all stakeholders over all phases of the project.

In this study, the main challenges within the current practice of project management are analyzed and what BIM-based project management has to offer to those challenges have been discussed. The thesis explores how BIM method can be applied to project management and how information can be collected to build a BIM model. The advantages of BIM-based scheduling (4D), cost estimation (5D), sustainability (6D), facility management (7D) and structural analysis in the scope of project management is discussed. A case study is given to validate the use of the computer aided programs for nD BIM during the construction phase.

ÖZET

YAPI BİLGİ MODELLEMESİ İLE PROJE PLANLAMA VE YÖNETİMİ

Bugün, inşaat uygulamalarında projenin büyüklüğü arttıkça etkili inşaat yönetim teknikleri ve araçları önem kazanmaktadır. Büyük ölçekli projelerde görev, parametre ve kısıtların artması ve bütün bunların etkileşimi projenin karmaşıklığını arttırmaktadır. Bu zorluklarla başa çıkabilen tekniklerin ve araçların araştırmaları devam ederken, son zamanlarda karşımıza çıkan Yapı Bilgi Modellemesi (YBM) yaklaşımı inşaat projelerinin karmaşıklığını verimli bir şekilde ele alabilmektedir. YBM, bir bina veya yapının 3 boyutlu olarak dijital canlandırmasını vermektedir. Geometrik verileri modellemesi yanında en önemli özelliği proje ile alakalı tüm anlamsal veri (elemanın işlevi, malzeme özellikleri, yapı detayları, iş programları vs.) YBM modeli içinde depolanır. Amaç, tek bir modelde projenin tüm aşamalarında yer alan tüm paydaşları birleştirmektir.

Bu çalışmada, başlıca ele alınan konu proje yönetiminin mevcut uygulamalar kapsamında analiz edilmesi ve YBM tabanlı proje yönetiminin bu zorlukları nasıl ele aldığının bir sunumudur. Bu tez YBM'nin proje yönetimine nasıl uygulanabileceğini be YBM modeli için nasıl yöntem ve bilgi toplanabileceğini araştırmaktadır. YBM tabanlı zamanlama (4D), maliyet tahmini (5D), sürdürülebilirlik (6D), tesis yönetimi (7D) ve yapı analizinin proje yönetimi kapsamında avantajları tartışılmıştır. Bilgisayar destekli bir vaka çalışması ile inşaat aşamasında nD YBM modeli oluşturulmuştur.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

2D	Two dimension
3D	Three dimension
4D	Three dimensions + time
5D	Three dimensions + cost
6D	Three dimensions + sustainability
7D	Facility Management
AEC	Architecture, Engineer, Construction
AIA	American Institute of Architects
BEP	BIM Execution Plan
BIM	Building Information Modeling
CAD	Computer Aided Design
CPM	Critical Path Method
EF	Earliest Finish
ES	Earliest Start
EV	Earned Value
EVA	Earned Value Analysis
gbXML	Green Building XML schema
GIS	Geographic Information System
HR	Human Resources
HVAC	Heating, Ventilation, Air Conditioning
IFC	Industry Foundation Classes
IPD	Integrated Project Delivery
IT	Information Technology
JIT	Just-In-Time
LCC	Life Cycle Cost
LEED	Leadership in Energy and Environmental Design
LF	Latest Finish
LS	Latest Start
LOD	Level of Development
M	Most Likely Time

MEP	Mechanical, Electrical, Plumbing
NBIMS	National Building Information Modeling Standards
O	Optimistic Time
P	Pessimistic Time
PERT	Program Evaluation And Review Technique
PM	Project Management
PMBOK®	Project Management Body of Knowledge
PMI	Project Management Institute
RFI	Request for Information
RSA	Robot Structural Analysis
PV	Photovoltaic Panel
WBS	Work Breakdown Structure
QTO	Quantity Take-Off

CHAPTER 1

INTRODUCTION

Today, in construction practice, implementation of effective construction management techniques and tools is becoming essential, especially as the scale of the projects increases. Construction project team manages the tasks, scope, time, cost, risk, and quality, in harmony, to assure successful application. Especially, large scale projects pose a challenge to industry; as the number of tasks, parameters and constraints to be considered increases, interaction of these tasks and parameters increases the complexity as well. While the search for techniques and tools for better coping with complexity will never end, building and construction industry are starting to abandon the traditional two dimensional (2D) method according to the necessities of 21st century and making transition to Building Information Modeling (BIM) which has recently emerged as an approach that achieves considerable improvement in efficiently handling complexity (Autodesk 2013).

In the construction industry, BIM has become a requirement to manage projects more effectively. Contractors have seen the benefits of BIM and want to adopt this process for managing their projects (Blažević, Vukomanović, and Radujković 2014). BIM is able to provide a digital visualization in 3D, but more importantly BIM systems store, besides geometric data, all necessary semantic data (function of the element, material properties, construction details, schedules, etc.) in the model and establishes a collaborative platform in the design and construction industry. Generally, design experts are managed the construction projects in the scope of time and cost. But a construction process consists of different project management skills like risk, quality or quantity estimation that need to be paid attention. Moreover, it is a single model of the project for all stakeholders (designers, planners, contractors, supervisors, consultants etc) over all phases of the project which gathers all project management (PM) skills around the same model. The benefits of the BIM technology begin at the conceptual design stage and cover the entire lifecycle (Bagdonas 2014, Abdirad 2015).

According to the literature review, the benefits of integrating project management (PM) and BIM can be seen. Chen et al. (2013) developed an automated and integrated project scheduling and management system and was obtained 7.6% of project time reduction (Chen et al. 2013).

With the new technological developments, some software has been developed for both visualization and work program preparation. One of these is 4D CAD which offers a tool to combine the work program with 3D CAD model. In this manner, the work program is made more comprehensible, and the progress of the construction program can be visualized and progresses can be followed until the finalization of the project. Besides, 4D CAD provides cost control, resource allocation, budget forecasting, and can be avoid errors and problems in the earlier stages. A case study of TT Arena Galatasaray Stadium is conducted by using 4D CAD applications in Turkey. The total construction area is approximately 70.000 m^2. This study is realized to give an insight and to introduce 4D applications to construction sector in Turkey because there are very few examples practiced on this topic. SWOT analysis and Power Area analysis were conducted with the cooperation of the company and researcher to decide and install the 4D software. The aim was to have knowledge about the implementation of 4D CAD software, to create a 4D simulation model and to analyze the problems encountered in the implementation of the 4D CAD software. Pareto analysis was performed to identify the problems. The main problem was the complexity of the high level of detail and the time spent for model preparation (Erdoğan 2009).

Candelario-Garrido et al. (2017) made a comparison between the traditional planning and 4D simulation through a variable-based assessment. Values from 33 companies were averaged. The companies were generated 4D simulations and involved the information of their present studies. Totally, 11 variables and their weight on the project were predicted. The variables are selected as execution time, planning difficulty, information viewing, documentation use in the office or in field, understanding documentation, information quantity and organization, change management and control, possibility of optimizing work performance, extraction of planning reports and updating ease. A numerical value ranging from 1 (unsatisfactory) to 5 (optimal) is selected. The weighted average of 4D simulation was rated 4 in contrast to conventional planning method which was rated 3.10. In total manner, according to the results of the weighted averages, 4D simulations were more effective than conventional planning methods. However, 4D simulation was more time-consuming during planning -as much as 20%-

than conventional case, whereas 4D simulation had significant effect in terms of project progress and visualization than traditional planning was quantified as 40% higher (Candelario-Garrido, García-Sanz-Calcedo, and Reyes Rodríguez 2017).

Bagdonas (2014) investigated a real life project by using BIM. A medical office building project generic price by the architects was investigated $19 million. The first estimation by Company was $22,250,000 and due to the help of automatically calculation by BIM, the final price accepted by the client was $19,573,000 and the final price of the project investigated $19,437,600 with adding value of $636,500 for the client. And the cost was reduced 15.6% from the first calculation. The price changes are updated in the total cost easily because BIM models calculate the cost automatically after any changes in the project. According to the estimators, BIM played a huge role in cost estimation. In addition, there were a lot of changes in the design during the construction. Even so, the deadline for the construction termination was not interrupted. The managers mentioned that if the project was realized more traditional way, the cost would be enormous and delays would occur (Bagdonas 2014).

Abanda et al. (2017) investigated ontology to adopt in BIM technology on the domain of 5D modeling and the challenges on cost estimations were discussed. In Finland, by adopting BIM technology; the profit margins increased 45%. In UK, a project which used BIM technology provided 20% of cost saving. In addition, BIM also has benefits for risk management. It reduced 5% the on-site accident rate in Finland. The main challenge in UK was the lack of ontology to undertake quantity take-offs and cost estimation compliant to the UK New Rules of Measurement. For this reason, an ontology-based approach was proposed (Abanda, Kamsu-Foguem, and Tah 2017).

In another study of Abanda et al. (2017), an integrated BIM to measure the embodied energy (the quantity of energy used during the lifecycle of materials during construction, renovation or demolition) and carbon dioxide (CO_2) assessment is examined. In the UK, the greenhouse emissions from construction industry were reported 47%. For this reason, the construction industry is responsible for a significant pollutant. Reducing embodied energy and CO_2 of buildings is a new topic amongst environmental organizations. It is a huge amount and must be cut according to the UK construction strategy report. By developing the building model with BIM tools, a BIM-based integrative framework was modeled to compute the embodied energy and CO_2 (Abanda, Oti, and Tah 2017).

Aziz et al. (2016) explained the opportunities of BIM for facility management. During the building life cycle, the highest expenditure is the operation and maintenance cost. The adoption of BIM model provides quick information and a database. The use of BIM in US Coast Guard Facility Planning case study reported 98% of time saving to create a database and update the facility data when BIM is used (Aziz, Nawawi, and Ariff 2016).

In this study, the main challenges within the current practice of project management process are analyzed and what BIM-based project management has to offer to those challenges have been discussed. This thesis aims to explore how BIM method can be advantageous in project management and how can be practically implemented and how information can be collected to establish BIM-based scheduling (4D), cost estimation (5D), sustainability (6D) and facility management (7D) in the scope of project management with lowering building Life Cycle Cost (LCC). A case study is presented to validate the use of the computer aided programs for nD BIM during the construction phase (Aðalsteinsson 2014).

This thesis is comprised of five chapters. First chapter presents an introduction; the second identifies the state of the art and the theory of project management and building information modeling, the third briefly analyzes a case study, the fourth lists the results and the fifth concludes the foundation of the thesis.

CHAPTER 2

LITERATURE REVIEW

This thesis presents project management based on BIM approach. Traditional methods of project management can be adopted and used more effectively using BIM technology. Due to a huge economy of construction industry all around the world, the methods are changing and should keep pace with these new trends (Jankowski, Prokocki, and Krzemiński 2015). Before the start, some expressions must be known by heart. For this reason, the literature review is divided into three parts. The first part is about project management; it explains what project management is, how it can be applied in the construction industry and what the benefits of project management strategy are. The topic of the second part is the description of BIM method. This part explores what is the BIM technology, how it can be used during the building project and how it can be used effectively on construction industry. Third part of the literature review is on PM and BIM integration. This part clarifies the structure of PM and BIM connection during the building lifecycle based on nD technology (Aðalsteinsson 2014).

2.1. Project Management (PM)

A PROJECT is defined as a temporary endeavor undertaken to create a unique product, service, or result by PMBOK (Project Management Body of Knowledge). PMBOK is an important and essential guide for construction professional issued by Project Management Institute. The project can be a product or service. If the description carefully examined, it can be said that temporary means the project beginning and end time which is specified with a schedule and unique means that the product or service must be a new thing to create a value for the stakeholders (Project Management Institute 2000).

The trend of the project management (PM) has shown a rise since the end of the 1980s. Researches concentrated on project management have improved day by day since the mid-1990. Since the 21st century, the combination of integrated theories and traditional disciplines of project management become widespread due to the managerial thinking which is emerged at the beginning of 20th century by Taylor and Fayol. Taylor and Fayol introduced their own organizational theories from their own experiences (Garel 2013).

Project Management knowledge areas show variety as integration management, scope management, schedule management, cost management, quality management, resource management, communications management, risk management, procurement management and stakeholder management. Each project contains a level of uncertainty according to these management areas. The challenge lies in managing these uncertainties without missing any of these knowledge areas (Project Management Institute 2017).

According to the definition, a project must meet a scope within a deadline and a budget. The aim of the PM is to satisfy the project goal with integrating scope (scope management), schedule (schedule management), and cost (cost management) within a quality (quality management) manner. This is called "triple constraint" or "iron triangle" of the project. Each corner of the triangle brings advantages and risks (risk management). Shortly, a project manager must be added a value to the project with using knowledge, tools and techniques to meet the project goal (Browning 2014, Radujković and Sjekavica 2017). All of these knowledge areas affect each other. If the scope is changed, time and cost will change immediately and it will affect the quality. It is like a domino effect (Project Management Institute 2000). During the project implementation, activities and deliverables are involving hierarchically in a logical relationship. Work Breakdown Structure (WBS) manages visually these deliverables to describe the scope of the project. Activities have to be sequenced to compose a schedule. It can be prepared manually or with the computer aid such as project management software. The important part to generate a schedule is to determine the duration of activities, start and finish dates.

To create a successful project management system, the important thing is the accessibility to information at the right time. It helps project professionals to make better decisions when needed (Aðalsteinsson 2014). Project professional groups can be counted as contractors, architects, engineers and project managers which have important

roles in construction (Elmualim and Gilder 2013). Basically, according to the PMBOK, project management process is divided into four basic phases as initiating, planning, executing - controlling and closing and can be seen in detailed in Figure 2.1 (Project Management Institute 2000). In each phase, project manager and other professionals have roles to play and have a lot of uncertainty to deal with. For this reason, using computer aided systems helps professionals cope with the responsibilities and improves collaboration (Elmualim and Gilder 2013, Aðalsteinsson 2014).
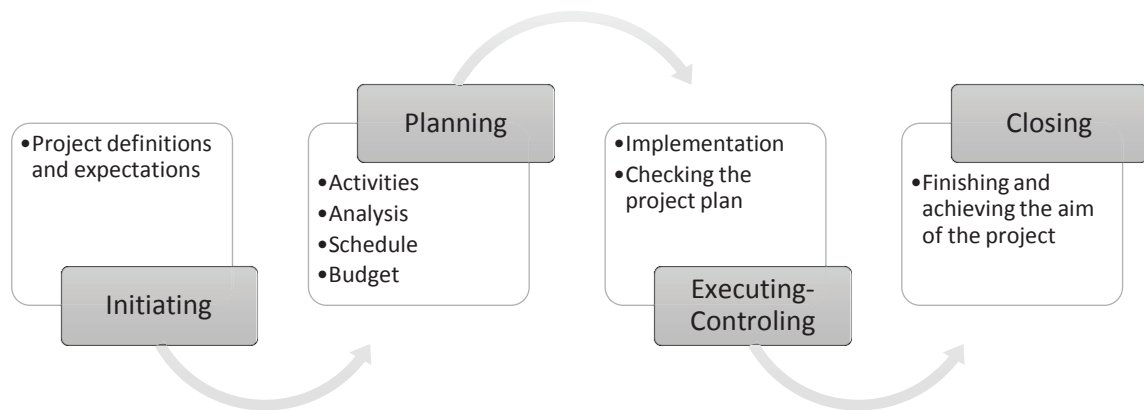
Figure 2.1. Project management process
(Source: Project Management Institute 2000)

Construction project stages are divided in 4 stages; Planning, Design, Construction, Operation and Maintenance which can be seen in Figure 2.2. Planning stage allows making analysis and programming of the project. At this stage, the regulations and legislations are collected and feasibility analyses are done (Azhar, Khalfan, and Maqsood 2012). Design stage involves site analysis, 3D presentation, design coordination, cost estimation, energy simulation and clash detection with the aid of BIM models (Cao et al. 2015). It can be divided into three detailed sections: *Schematic Design* where options are analyzed, *Detailed Design* where 3D models including details for structural, mechanical, electrical systems are completed, and *Construction Detailing* where scheduling (4D) and cost estimations (5D) are done to provide an insight for construction stage (Azhar, Khalfan, and Maqsood 2012). Construction stage consists of fabrication, schedule simulation, quantity take-off, site resource and supply chain management and fabrication to carry out the activities

planned during the planning stage. Operation and management stages include the management of the jobsite (Azhar, Khalfan, and Maqsood 2012, Cao et al. 2015).

2.1.1. PM Tools and Techniques

Network representations have many benefits for project management. Networks demonstrate how project activities can be organized to determine the duration of the project. Graphical project management network techniques are Critical Path Method (CPM), Gantt Chart and Program Evaluation and Review Technique (PERT). The tasks to be performed are decided at the planning stage. These techniques generate time-oriented diagrams. Before to use these techniques, the starting and end dates, durations and milestones must be arranged (Winston and Goldberg 2004).
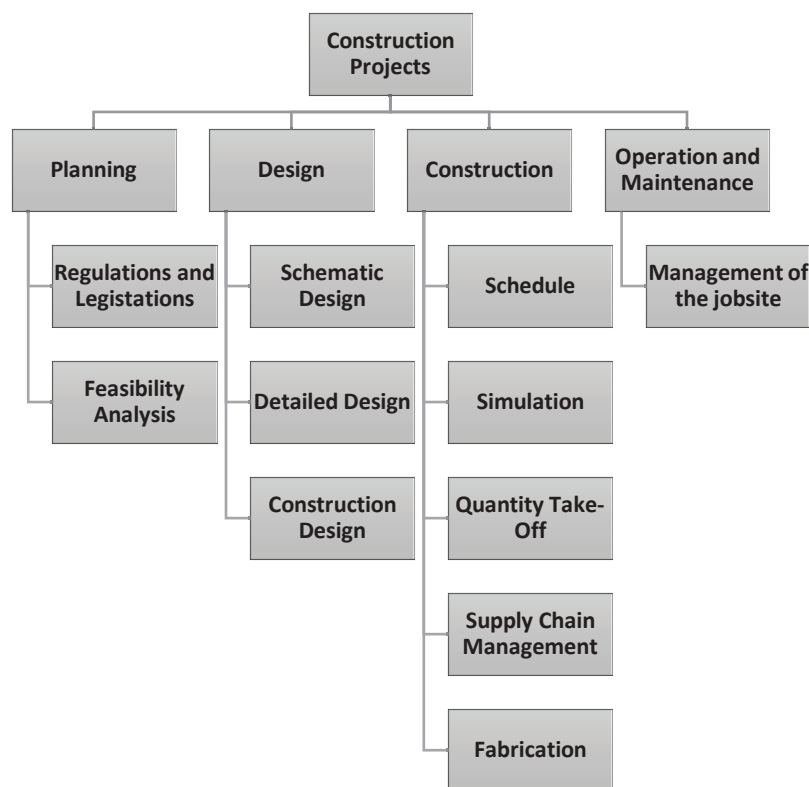
Figure 2.2. Construction project stages
(Source: Azhar, Khalfan, and Maqsood 2012, Cao et al. 2015)

Another objective tool to predict the schedule and cost performance is Earned Value Analysis (EVA). EVA demonstrates a real time cost estimation in accordance with the construction. It makes a performance comparison between the values of work and cost performed (Acebes et al. 2015).

The most commonly used software packages are MS Project and Primavera. These software packages can be used to produce schedules with sequencing the activities by assigning resources to tasks and analyze the workloads. Critical pathway, Gantt chart and PERT diagram can be created easily. Also MS Excel can be utilized to implement these methods.

2.1.1.1. Critical Path Method (CPM)

The Critical Path Method (CPM) is a procedure to identify set of tasks with a minimum amount of time which is called the critical path. It is described that the task sequence will be completed without any delay. If a delay occurs, the project will be separated from critical path and the time to complete entire project will prolong (Baker et al. 2012).

To create a CPM, all activities, milestones, tasks, deadlines, deliverables and constraints like budget, equipment and holidays must be listed at planning stage. For each activity; duration, predecessor and successor and resources as money and equipment/procurement will specify. After to create these properties, a CPM chart can be generated (Grover 2002, Baker et al. 2012).

Firstly, the earliest start (ES), earliest finish (EF), latest start (LS) and latest finish (LF) times must be determined. The main point to identify the critical path is to equalize the ES and LS. The evaluation is started with the task which is not included any predecessor. If there is no predecessor, the earliest time of the task is zero. Secondly, a forward pass must be observed after the completion of the predecessor activity. The sequence of the operations is from left to right. The ES value for the next activity is equal to the maximum value of EF from predecessor. Thirdly, a backward pass can be done. This time, the sequence of the operations is from right to left and the LF and LS is filled. Contrary to the second step, LS can be found by LF minus duration.

And the LF of the predecessor activity will be the minimum value of LS from successor. Finally, the critical path can be determined at the boxes when ES is equal to LS. At this route, there is no slack or waste of time for the project. The total project completion time on critical path gives the minimum completion time of the activities. Critical path can be expressed as the longest route in the network. The calculation method can be seen in Equation 2.1, 2.2 and 2.3 (Hillier and Lieberman 2001, Level 2015). Figure 2.3 shows a CPM network diagram which includes all necessary information to determine to critical path. The critical path can be estimated as A - B - C - E - F - G which is seen in red arrow.

$$EF = ES + \text{duration of the activity} \qquad (2.1)$$

$$LS = LF - \text{duration of the activity} \qquad (2.2)$$

$$Slack = LS - ES = LF - EF \qquad (2.3)$$

With using Primavera, MS Project or MS Excel, thousands of activities and WBSs can be arranged easily to create the critical path (Baker et al. 2012).
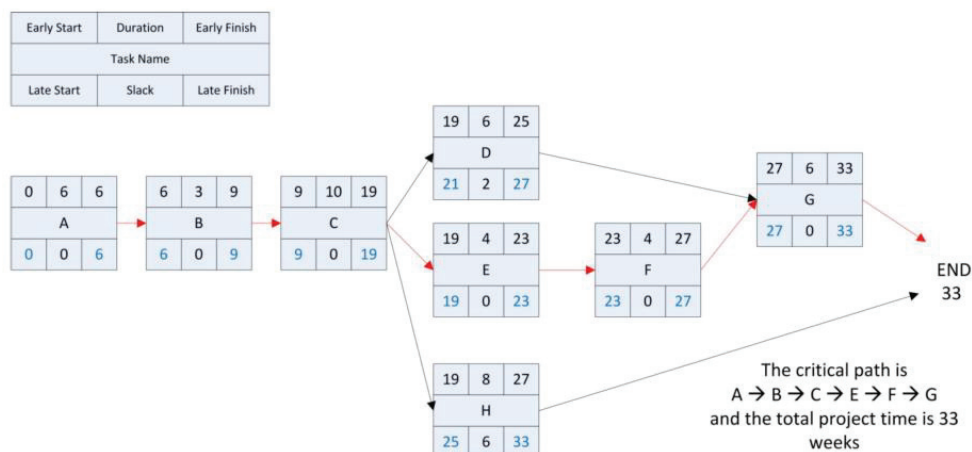
Figure 2.3. CPM network diagram
(Source: Hillier and Lieberman 2001)

10

2.1.1.2. Gantt Chart

A Gantt chart is a project scheduling diagram which is figured out the activities in a horizontal bar chart. Each bar demonstrates a task which depends on calendar. Contrary to CPM, a Gantt chart does not show the critical path but the connection between the tasks can be linked by lines. Figure 2.4 show a Gantt chart example (Baker et al. 2012, Level 2015).

Tasks are sorted on the left of the chart from top to bottom according to the occurring time. The activities, beginning and end dates, activity durations and relationship between the activities can be seen at the chart (Grover 2002). The main importance is to track the schedule progress. The estimated dates of the activities and the actual work dates can be identified by using Gantt chart. It gives an easy look to understand how the project is advanced and the "what if" scenarios can be seen if any delay occurs, how long the schedule will be elongated or how much the cost will be increase (Maserang 2002).

Figure 2.4.Gantt chart example
(Source: Level 2015)

2.1.1.3. Program Evaluation and Review Technique (PERT)

Project durations cannot be certain. Program Evaluation Review Technique (PERT) is used for probabilistic activity durations. Contrary to CPM which is a deterministic method, PERT method is more probabilistic. In CPM, it is assumed that

the duration of the activities is known. But in PERT, the duration of the activity is modeled as a random variable. Three estimates as optimistic time (O), most likely time (M) and pessimistic time (P) are used to provide expected time (T_E) and variance of the activity. Optimistic time can be defined as the shortest time for the activity which has a small probability. Most likely time can be described as the task should be finalized within this predicted time. Pessimistic time can be identified as the task will be completed certainly within this time. Expected time (T_E) (mean) and variance (σ^2) are calculated as the mean of the beta probability distribution. PERT assumes that the duration of the activities is independent (Hillier and Lieberman 2001, Winston and Goldberg 2004, Level 2015).

$$T_E = \frac{O + 4M + P}{6} \qquad (2.4)$$

$$\sigma^2 = \frac{P - O^2}{6} \qquad (2.5)$$

2.1.2. Integrated Project Delivery (IPD)

To manage all nine knowledge area of project management in a harmony, project must complete successfully. For this reason, a systematic project delivery approach must be followed in the construction projects to meet the requirements of the project goal (Banaitiene and Banaitis 2012). Integrated Project Delivery (IPD) is a solution-oriented approach which can be applied at the entire life cycle of the project. Briefly, IPD is method is an integrated framework of the project like a roadmap to systemize the project which integrates people in a collaborative manner to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction by American Institute of Architects (AIA). The difference also came from linking the time, cost or other constraints data into the 3D model. It is similar with BIM approach (AIA National 2007, Anderson 2010, Mihic, Sertic, and Zavrski 2014, Jones 2014).

Table 2.1 demonstrates a summary of PM knowledge areas. Each knowledge area contains in itself different concepts but the common knowledge of them is a control

mechanism. It is performance control mechanism which must be monitored to make a situational analysis. Each control gives feedbacks to take precautions. Table 2.2 shows the integration of the knowledge areas with the project management stages. It should customize the process for each stage (Project Management Institute 2000).

2.2. Building Information Modeling (BIM)

Each project contains a level of uncertainty according to the management areas mentioned above. The key performance indicator is to manage these uncertainties without missing any managerial issues. The concepts underpinning BIM were first introduced by Eastman in the mid 1970s with the "Building Description System (BDS)" prototype. After Eastman's paper, the development of BDS continued in different places around the world with different descriptions. USA based efforts mentioned "Building Product Models" and European efforts investigated "Product Information Models" during the 1970s and 1980s. First documented use of the term "Building Modeling" in the sense we use today was by Robert Aish (1986). Van Nederveen and Tolman were first to use "Building Information Model" in their articles in 1992 and Jerry Laiserin was the first to use and popularize the term "BIM" ((Eastman et al. 2008, Quirk 2012).

2.2.1. BIM Method

BIM is an intelligent model which is able to provide a digital visualization and shared knowledge area in 3D, but more importantly BIM systems store, besides geometric data, all necessary semantic data (function of the element, material properties, construction details, schedules, etc.) in the model to facilitate the project management. Moreover, it is a single model of the project for all stakeholders over all phases of the project. The benefits of the BIM technology begin at the conceptual design stage and cover the entire lifecycle (Abdirad 2015). BIM establishes a collaboration process in the design and construction industry which gathers all PM skills around the same model (Bagdonas 2014, Fleming 2016).

Table 2.1. Summary of PM knowledge areas

(Source: Project Management Institute 2000, 2017)

PM Knowledge Areas	Definition	Subsets	
Project Integration Management	Ensure the coordination of the project.	Develop project charter	Predict the goal of the project.
		Develop project management plan	Create a document to integrate and coordinate the project throughout the project life cycle.
		Direct and manage project work	Manage the day to day work of the project.
		Manage project knowledge	Manage project knowledge.
		Monitor and control project	Effective project control.
		Perform integrated change control	Coordinate the change throughout the life cycle.
		Close project or phase	Final report, result transition.
Project Scope Management	Precise clearly the scope.	Plan scope management	Develop a written scope statement.
		Define scope	Divide into subtasks the project activities to facilitate the management.
		Collect requirements	Determine, document, and manage stakeholder needs and requirements to meet objectives.
		Create WBS	Create a formal document of project scope.
		Validate scope	
		Control scope	Control of the changes within the project scope and expectations.
Project Schedule Management	Ensure to finish the project on time.	Plan schedule management	Creation of a schedule management plan
		Define activities	Determine the activities.
		Sequence activities	Set the relation between the activities; create successor and predecessors.
		Estimate activity durations	Estimate the work hour/day/week/year of the activities.
		Develop schedule	Create the project schedule.
		Control schedule	Control of the changes within the project schedule based on time objective constraint.
Project Cost Management	Ensure to finish the project with the approved budget.	Plan cost management	Identify the resources and its quantities. The resources can be people, material, equipment or money.
		Estimate costs	Estimate the cost of the resources.
		Determine budget	Estimate the overall cost of the project.
		Control costs	Control of the changes within the project budget based on cost constraint.
Project Quality Management	Ensure the requirements and standards of the project.	Plan quality management	Precise quality standards.
		Manage quality	Satisfy the quality standards.
		Control quality	Control of the changes within the project quality to monitor if the quality standards or requirements are provided.

Table 2.1. (cont.)

PM Knowledge Areas	Definition		Subsets
Project Resource Management	Coordinate a project	Plan resource management	Precise the type and quantity of resources.
		Estimate activity resources	Resource requirements, resource breakdown structure.
		Acquire resources	Physical resource assignment and project team assignment.
		Develop team	Improve the group performance.
		Manage team	Manage the strength and weakness of the project resources.
		Control resources	Measurement of the productivity.
Project Communications Management	Coordinate the communication network on work site.	Plan communications management	Identify the communication type of the stakeholders.
		Manage communications	Provide necessary data on time to stakeholders.
		Monitor communications	Measurement of the progress and productivity.
Project Risk Management	Analyze the project risks.	Risk management planning	Decide for the risk management activities.
		Identify risks	Identify and document the risks.
		Perform qualitative risk analysis	Make a qualitative analysis of risks.
		Perform quantitative risk analysis	Estimate statistically the effect of the risk.
		Plan risk responses	Identify procedures, techniques and standards to reduce project risks.
		Implement risk responses	Update project documents.
		Risk monitoring and control	Measurement of the project risks.
Project Procurement Management	Provide the procedures to purchase goods and services for the project.	Plan procurement management	Plan the requirements of the site.
		Conduct procurement	Procurement execution.
		Control procurement	Control the requirements, bids and offers.
Project Stakeholder Management	Identifying each stakeholder and making sure they're happy.	Identify stakeholders	Identification of the major and minor stakeholders.
		Plan stakeholder engagement	Identify and analyze stakeholder's the level of interest and the ability to control.
		Manage stakeholder engagement	Stakeholder interaction.
		Monitor stakeholder engagement	Review of stakeholder communication and gather information.

Table 2.2. The relation between the PM knowledge areas and PM process stages (Source: Project Management Institute 2000, 2017)

Knowledge Area	Initiation	Planning	Executing	Monitoring & Controlling	Closing
Project Integration Management	Project charter development	Project Plan	Manage Project Knowledge	Integrated change control	Close project
Project Scope Management		Define scope management Collect requirements		Scope change validation and control	
Project Schedule Management		Define, estimate, develop the schedule		Schedule control	
Project Cost Management		Budget determination		Cost control	
Project Quality Management		Quality standards	Manage quality	Quality control	
Project Resource Management		Resource management planning Resource estimation	Acquire resources and team development	Control resources	
Project Communications Management		Communication plans	Team collaboration	Performance controlling and monitoring	
Project Risk Management		Risk analysis	Implementing risk responses	Risk control	
Project Procurement Management		Procurement procedures	Procurement	Control procurement	
Project Stakeholder Management	Stakeholder identification	Stakeholder engagement planning	Manage stakeholder	Controlling and monitoring stakeholder engagement	

Figure 2.5 summarizes the BIM approach. BIM covers the project before, during and after the construction. This is called a project life cycle. A project life cycle covers conceptual design, detailed design, analysis and documentation, fabrication, schedule, cost, logistics, operation and maintenance, renovation and demolition. BIM reduces the design, build and operation complexities with better coordination and collaboration throughout the project life cycle with storing all information about the model elements in the electronic format (Bryde, Broquetas, and Volm 2013).

Software developers create different BIM programs. Autodesk Revit[®], Autodesk Naviswork[®], Trimble Tekla[®], Nemetschek Allpan[®] and Graphisoft ArchiCAD[®] are the software and companies which developed BIM software (Bagdonas 2014, Alizadehsalehi, Koseoglu, and Celikag 2015).
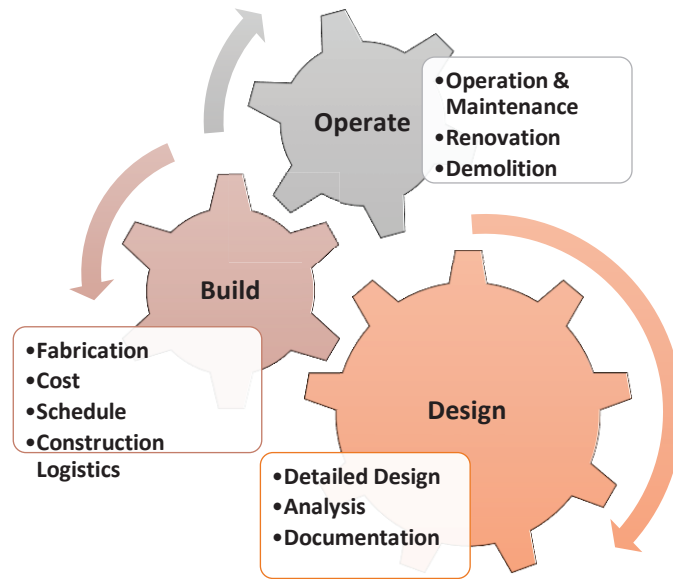
Figure 2.5. BIM life cycle cover

(Source: Amireddy 2014)

The main difference between BIM and conventional computer aided design (CAD) technology is that the BIM technology provides a 3D model of the building from which plans, sections and elevations are automatically generated. It is very easy to change or edit a component since all views are updated automatically. Also the model includes data and creates smart objects which have physical and functional characteristics (Azhar, Khalfan, and Maqsood 2012). Thus BIM is able to hold all necessary data and provides a platform for information management for the whole project during the life cycle, reducing time, costs and delays (Brokaw and Mukherjee 2012).

Key terms of BIM applications are classified by multidimensionality. The multidimensionality enhances the project productivity and facilitates the managerial knowledge areas. Each D represents a constraint which must be managed.

The fourth dimension (4D) demonstrates time in addition to 3D model, the fifth dimension (5D) identifies cost within the model, the sixth dimension (6D) provides sustainability of the project within the project life cycle and the seventh dimension (7D) involves the facility management especially after the construction stage. The details about n dimension (nD) will be given in the following sections. But a summary can be seen in Figure 2.6. The development of the BIM technology is adopted by the Architecture - Engineering - Construction (AEC) industry. It can be classified as a

technology and a process. The technological part represents the intelligence of the model and collaborative visualization. The process part identifies design, construction or operational stages (Azhar, Khalfan, and Maqsood 2012, Bloomberg, Burney, and Resnick 2012). The collaboration of the BIM serves an integrated design to project stakeholders. Thus, an architect or an engineer can produces feedbacks immediately or realizes any conflicts on the virtual model before the construction. In this way, the changes can be predicted in the earlier design stages and optimizes simultaneously (Azhar and Brown 2009, Alizadehsalehi, Koseoglu, and Celikag 2015).

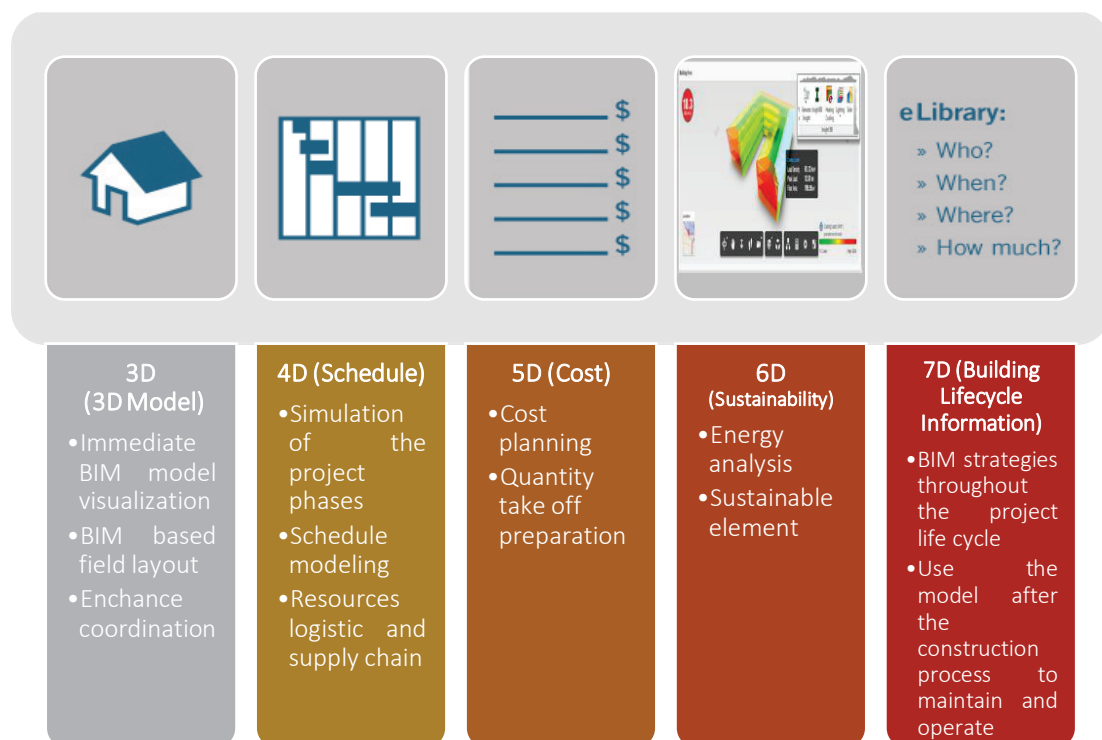| 3D (3D Model)	4D (Schedule)	5D (Cost)	6D (Sustainability)	7D (Building Lifecycle Information)
•Immediate BIM model visualization •BIM based field layout •Enchance coordination	•Simulation of the project phases •Schedule modeling •Resources logistic and supply chain	•Cost planning •Quantity take off preparation	•Energy analysis •Sustainable element	•BIM strategies throughout the project life cycle •Use the model after the construction process to maintain and operate

Figure 2.6. Key terms of BIM
(Source: Hughes 2013)

As mentioned before, a project must add a value to project. Thus, BIM utilization should also create a value. Table 2.3 below shows the value of BIM in each step of the project which is summarized by New York City Department of Design and Construction as a BIM Guidelines (Bloomberg, Burney, and Resnick 2012).

Table 2.3. BIM value on project

(Source: Bloomberg, Burney, and Resnick 2012)

Project Step	BIM Necessity	The Added Value
Existing Conditions Modeling	3D Model and smart elements creation with all information.	• Provide documentation about existing conditions • 3D visualisation
Site Analysis	Analyze the field to determine geographic information system (GIS) data.	• Decision for the compliance of the site with the project goal • Determine technical and financial project requirements • Identify demolition needs
Programming	Design and plan drafts, standards and regulations.	• Evaluation of design on customer's request
Engineering Analysis	Use of BIM software to model and analyze.	• Engineering designs • Create energy effective model
Design Authoring	Create BIM collaboration and communication standards.	• Better control and quality with all stakeholders at the same network • Automatic schedule and budget preparation
Clash Detection	Eliminate the conflicts prior to installation.	• Eliminate the conflicts • Decrease of the construction duration and cost
Scheduling	Identify milestones, WBSs and activities for schedules.	• Evaluate critical path • Manage the resources optimally
Cost Estimation	Compose cost and quantity take offs	• Estimate the overall cost to compare if the budget is satisfied • Automatic QTO preparation
Construction System Design	Analyze the purchasing of the construction and provide safety.	• Enhance the productivity • Raise the conscious of safety
Sustainability Evaluation (LEED)	Leadership in Energy and Environmental Design (LEED) green building certification.	• LEED certification • Improve building performance by decreasing the energy use, increasing the indoor air quality

2.2.1.1. Advantages

The advantages of BIM technology are acceleration of project completion, accessibility to different phases, better coordination and control, better visualization, integrated energy analysis, simpler clash detection, effective collaboration through cloud access, robust data collection, data enrichment, object oriented and smart models (Aðalsteinsson 2014) and decreased overall cost (Azhar and Brown 2009). BIM promises to increase accuracy, improve efficiency and simplify management of projects.

The benefits of adopted BIM in the project can be sorted in Figure 2.7 and Table 2.4 below shows the long-term and short-term benefits of BIM technology.

Figure 2.7. The benefits of BIM technology
(Source: Bloomberg, Burney, and Resnick 2012)

Table 2.4. The long-term and short-term benefits of BIM technology
(Source: Autodesk 2013)

Long-term benefits	Short-term benefits
Provide business continuity	Fewer mistakes
Shorter project duration	Marketing of new jobs
High profits	Shorter the need of re-work
Decrease overall cost of the construction	Shorter workflow
Fewer complaints and litigation	Employment

2.2.1.2. Risks and Barriers to Implement BIM

On the other hand, BIM also has risks and barriers such as lack of standardization, legal and contractual risks, and lack of skilled personnel (Abdirad 2015). Moreover, lack of interoperability is still an issue. While most data transfer issues can be handled by using Industry Foundation Classes (IFC) format, many applications still does not fully support the standard (Aram, Eastman, and Sacks 2013).

This list can be categorized as technology-related risks and process-related risks and it can be classified on Table 2.5 below (Azhar, Khalfan, and Maqsood 2012).

Table 2.5. Risks and barriers to implement BIM
(Source: Azhar, Khalfan, and Maqsood 2012)

	Technology-related Risks	**Process-related Risks**
Risks	Lack of BIM standardization	Legal risks
	Lack of formatting	Contractual risks
	Interoperability	Organizational risks
	Lack of qualified personnel	Lack of collaboration
Effects	Inconsistencies	Conflicts
Solution	Adopt IPD to manage the collaborative work	

2.2.2. BIM Information Levels - Model Level of Development

BIM models consist of different information at different stages. For this reason, a standard about the details and minimum requirements on each stage is published by AIA. It is called "The Model Level of Development (LOD)" which describes 5 levels from LOD100 to LOD500. These levels are cumulatively collected (Bloomberg, Burney, and Resnick 2012). Table 2.6 below describes the details about LOD levels and Table 2.7 gives an example of the LOD for columns.

2.2.3. BIM Stages

Due to the lack of an international BIM standard, each country adopts different BIM stages. BIM maturity model is defined by Unite Kingdom (UK). This model proposes technological aspects of BIM to guide the project stakeholders based on different standards. The maturity model is consisting 4 level which starts with Level 0 to Level 3. In 2016, UK construction industry has brought necessity to use this model minimum on Level 2 for all public construction projects. The details about the Levels is summarized in Table 2.8 (Fleming 2016).

Table 2.6 Detailed information about LOD

(Source: Bloomberg, Burney, and Resnick 2012, AIA 2008)

LOD	Requirements	Analysis	Schedule	Cost	Other specifications	Design Phase
LOD100	3D parametric massing elements: area, height, volume, location, and orientation.	Analysis based on area and volume.	Specific scheduling.	Cost estimation based on area and volume.	Site analysis Topographic info. Building function	**Preliminary design (Pre-Schematic design): Conceptual Design - Massing and concept.**
LOD200	Generic elements: quantities, size, shape, location, and orientation.	Analysis of specific project performance.	Detailed schedule.	Cost estimation of construction based on volume and quantity.	Quantity take-offs based on thickness and width.	**Schematic Design: Approximate geometry**
LOD300	Assembly elements: quantity, size, shape, location, and orientation	Analysis of specific project performance.	More detailed schedule.	Cost estimation based on specific information.	Construction drawings, reports and charts. Quantity take-offs based on materials.	**Developed Design: Precise geometry.**
LOD400	Accurate model: The model includes all construction details as materials, notes, tags, colors or other specifications.	Structural analysis, energy analysis, clash detection, cost analysis.	Well-defined schedule.	Cost estimation as actual cost.	Virtual simulations. 2D and 3D drawings. Clash detection. Ready to tender.	**Final Model - Fabrication: Completion of Construction/ Representation of the proposed elements.**
LOD500	Constructed model	The mock-up.	Visualization. Linking the model and the schedule.	Cost integrated model.	3D coordination.	**Maintenance of the project. As-built model.**

But the common general qualification is to classify project life cycle phase, the scope and objective of BIM models from the beginning of the project to the end of construction. BIM has six specific stages/phases (conceptual design, preliminary design, detailed design, contract tendering, construction and post construction) which define different model completion specifications that can be summarized as follows (Abramova 2015). Figure 2.8 summarizes the BIM stages and the equivalent of LOD.

The phase names are changed during the integration of BIM systems. For this reason a summary table (Table 2.9) was prepared to understand which traditional construction phases are equivalent to BIM phases.

Table 2.7. LOD necessities example for columns

(Source: Bloomberg, Burney, and Resnick 2012)
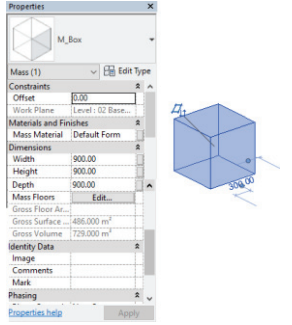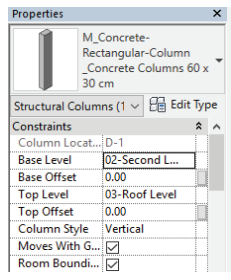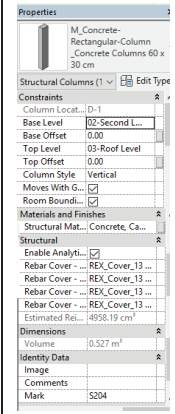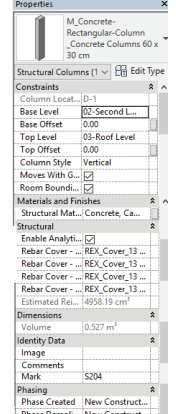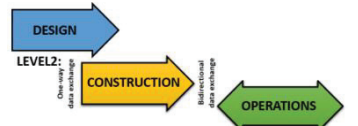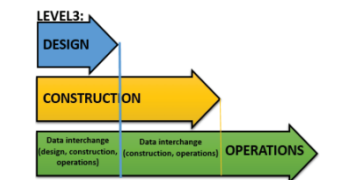
Requirements	LOD100	LOD200	LOD300	LOD400
Type/Dimension	x	x	x	x
Base Level	x	x	x	x
Base Offset	x	x	x	x
Top Level	x	x	x	x
Top Offset	x	x	x	x
Room Bounding		x	x	x
Material			x	x
Mark			x	x
Phase created				x
Phase demolished				x

Table 2.8. BIM maturity levels by UK

(Source: Aðalsteinsson 2014, Fleming 2016)

BIM Maturity Levels	Description	
Level 0 (or Stage 0)	2D CAD drawings and data exchange processes between the project owner and project designers.	
Level 1(or Stage 1)	2D or 3D CAD drawings based on UK Standard BS1192:2007 and financial management.	
Level 2 (or Stage 2)	Smart 3D BIM model with managed information and 4D scheduling and 5D cost estimation.	
Level 3 (or Stage 3)	Collaboration between the BIM tools.	

| Project Programming / Conceptual Design=PLAN =LOD100 |
| Project Design - Preliminary Design - Early Design=LOD200 |
| Preconstruction Phase - Detailed Design = DESIGN=LOD300 |
| Contract tendering=LOD350 |
| Construction Phase = CONSTRUCT =LOD400 |
| Post construction Phase - Takeover = OPERATE =LOD500 |
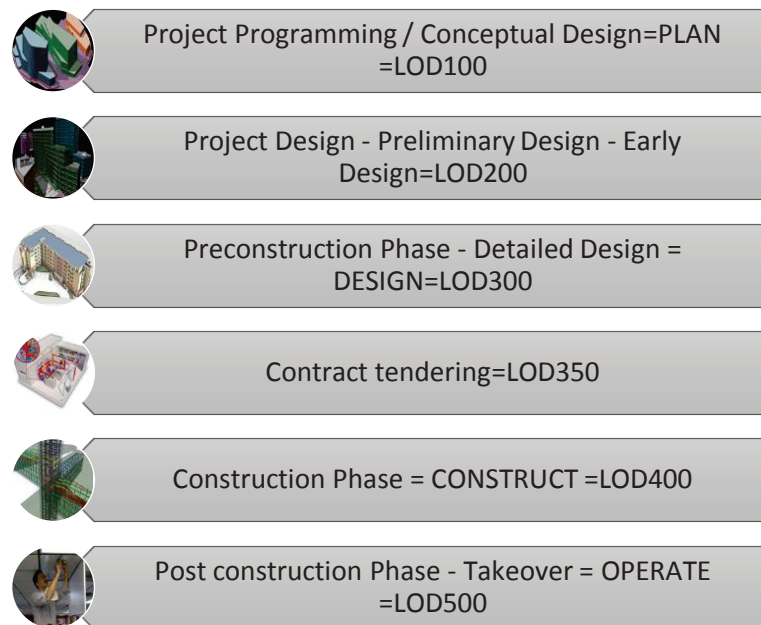
Figure 2.8. BIM phases vs. LOD

Table 2.9. Traditional vs. integrated construction phases
(Source: Rumane 2017)

Traditional	Pre-design	Schematic Design	Design Development	Construction Documents	Agency Permit/Bidding	Construction
Integrated	Conceptual Design	Criteria Design	Detailed Design	Implementation Documents	Agency Coord/Final Buyout	Construction

2.2.3.1. BIM and Project Programming - Conceptual Design

Project programming or conceptual design or planning is the first phase of BIM adoption. These three descriptions are synonyms. It contains basic information about the project type, classification (Aðalsteinsson 2014) and value - added activities (Azhar, Khalfan, and Maqsood 2012). This phase includes the objective and decision of the project (Azhar, Khalfan, and Maqsood 2012). The minimum requirements of the project in the conceptual design stage can be listed below (Abramova 2015):

- Information about the construction
- The size and shape

24

- The functionality of the rooms
- Loads, durability and safety of the building
- Lightening requirements
- HVAC requirements
- Indoor air quality and insulation requirements

2.2.3.2. BIM and Project Design - Preliminary Design - Early design

Project design or preliminary design or early design is the same and second phase of BIM. It is an important phase of project work flow. It is a proposal to create the 3D model, to make a decision, to build the model and to make an early tender. This phase is more developed and informed than the previous one. The main idea of this phase is the collaboration and coordination between the stakeholders. Each stakeholder prepares their BIM model (Aðalsteinsson 2014, Bagdonas 2014, Abramova 2015). The minimum requirements of the project in the preliminary design stage can be listed below (Aðalsteinsson 2014):

- Physical properties of the elements (walls, slabs, columns, beams...)
- Functional properties of the elements
- Structural properties of the elements
- Thermal insulation

2.2.3.3. BIM in the Preconstruction Phase - Detailed design

The third stage is called preconstruction phase or detailed design. At this stage, the main part of the building is determined. The analysis is done and necessary permissions are obtained (Aðalsteinsson 2014). The minimum requirements of the project in the detailed design stage can be listed below (Azhar and Brown 2009, Aðalsteinsson 2014, Abramova 2015, Cao et al. 2015):

- Architectural drawings

- Structural drawings

- MEP drawings

- Integrated project between the architectural, structural and MEP systems

- 3D model visualization

- Building permissions and forms

- Technical specifications

- Cost estimation

- Collaboration

- Sustainable design - Energy analysis

2.2.3.4. Contract tendering

Contract tendering is a sub stage of BIM phases. At this stage, quantity take-offs bills and overall cost will be precise. The tendering between the owner and contractor is realized (Abramova 2015).

2.2.3.5. BIM in the Construction Phase

The fifth phase of BIM is the construction phase. At this phase, management of the construction, supply chain, logistic, production based on cost. The generation of the requirements which listed below is very easy by using BIM tools. The minimum requirements of the project in the construction stage can be listed below (Aðalsteinsson 2014, Cao et al. 2015):

- Architectural drawings

- Structural drawings and design

- MEP drawings and design

- Detailed drawings

- Schedule simulation

- Cost estimations
- Quantity take-offs
- Eliminate the conflicts
- Logistic management based on the schedules
- Supply chain management based on the schedules
- Fabrication

2.2.3.6. BIM in the Post-construction Phase - Takeover

The last phase is the post construction phase or takeover where the construction is completed and becomes as-built model. This is the final model which includes all changes. It helps to manage the facility (7D) (Aðalsteinsson 2014, Abramova 2015).

2.2.4. BIM Execution Plan

BIM Execution Plan (BEP) can be defined as a detailed plan of carrying out a construction project using BIM technologies. It involves execution, monitoring and control steps with respect to BIM technology. This plan is specific and defines the goals to each project and planned at the beginning of the project. It can be updated at each stage in the scope of utilization. It is an important plan to manage and integrate the deliverables of the project. BEP identifies BIM goals, and BIM uses to achieve the goals, specifies the tools to be utilized, responsibilities of each team member and collaborator and protocols for information exchange. It also identifies key performance indicators to track progress. In BEP, BIM act as a managerial tool to achieve the goals (Bloomberg, Burney, and Resnick 2012). It is a document which demonstrates a framework for the processes and procedures to manage and coordinate the information needed. This plan provides detailed information about how the model can achieve success in the construction phase, how the project will complete on time with minimum conflict, which data is needed and when the necessary data will be used (Bloomberg, Burney, and Resnick 2012, Aðalsteinsson 2014).

It is an intensive and unique plan for each project. BEP document content includes the followings (Baker et al. 2012, Authority 2013):

- Strategic project goals
- Project information
- Roles and responsibilities of project members for different stages
- Qualification of the team members
- BIM integration for each stages
- Model elements for each BIM deliverable
- LOD for each BIM deliverable
- Collaboration to exchange the information and the procedure for communication
- The procedure for maintenance of the building
- Technical aspects
- The language of the contract

According to BIM Project Execution Planning Guide developer by The Computer Integrated Construction Research Group at Pennsylvania State University, the BEP planning procedure was predicted. The manual describes the four main steps of BEP implementation and demonstrates the requirement of each main step (Baker et al. 2012, Messner et al. 2010).

2.2.5. BIM Benefits for Project Stakeholders

Owners, designers (architect and engineers), contractors and project managers create project stakeholders. The benefits of BIM for project stakeholders can be listed as follows in the Table 2.10 (Azhar, Khalfan, and Maqsood 2012).

2.2.5.1. Project Owners

The initialization of a project starts with the idea of Project Owner. This idea is shared with other stakeholders. Thus, this idea becomes a model with the aid of

designers, transform to a building by contractors and carry out with a harmony by project manager. BIM has many benefits for project stakeholders as well as for project owners as is known. The benefits of BIM for project owners were summarized by Eastman and Reddy can be said as follows (Azhar, Khalfan, and Maqsood 2012):

- Provide project requirements for early design
- Ensure project visualization and simulation
- Predict overall cost estimation
- Reduce the conflicts and changes, hence ensure timely completion of the project
- Create 3D renders and animation to make effective marketing
- Above all, integrate and gather all information about the project in a single file all of these benefits as mentioned above

Table 2.10. BIM benefits for project stakeholders
(Source: Azhar and Brown 2009)

BIM Techniques	Owners	Designers	Contractors	Project Manager
Visualization	x	x	x	x
Project analysis		x	x	
Parametric modeling		x		
4D Scheduling		x	x	
5D Cost estimation	x	x	x	x
5D Quantity Takeoff		x	x	x
6D Sustainability	x	x		
7D Building Management	x			x
Site Logistic and Supply Chain			x	x
Building Performance Analysis	x	x	x	x

2.2.5.2. Project Designers

Project Designers consist of architect, civil engineer, mechanical engineer and electrical engineer. Their task is to analyze the project structure and to create alternative design. Designer team should create the requirement of owner. To provide accurate

information about the project, BIM takes advantages for schematic design, detailed design and construction stage. The advantages of BIM for project designers can be summarized as follows (Azhar, Khalfan, and Maqsood 2012):

- Better design and coordination
- Ensure project visualization and simulation
- Provide detailed project information from owners
- Better compliance: Clash detection
- Create easily drawings, elevations, schedules...
- Sustainability analysis
- Building performance analysis

2.2.5.3. Project Contractors

Contractors and subcontractors adopt and use BIM method according to the benefits given below (Azhar, Khalfan, and Maqsood 2012):

- Facilitate to create schedules
- Facilitate to estimate overall cost
- Facilitate to create quantity takeoffs
- Eliminate the conflicts and omissions by clash detection
- Manage and monitor the activities
- Manage logistic activities
- Provide supply chain integration
- Create site safety and risk plan
- Better coordination and communication with other stakeholders
- Implement the construction

Contractors must deliver outputs at as-built stage to prepare the building for 7D. The outputs shall be site technical specifications, BIM manuals and warranties (Aðalsteinsson 2014).

2.2.5.4. Project Manager

Project Manager coordinates all the project deliverables as materials, equipment and resources as workers, money to create a harmony between the project schedule and budget. It is hired by contractor and reports every step of construction to owner, designer and contractor and has a key role on the project. BIM has also some benefits for Project Managers as well as the benefits which mentioned above (Azhar, Khalfan, and Maqsood 2012, Baker et al. 2012, Bryde, Broquetas, and Volm 2013).

- Provide better outputs
- Facilitate access to right information on the right time by smart phones and tablets
- Provide integration of the project
- Act as a bridge between the site and contractor
- Stimulate the site team
- Above all, integrate and gather all information about the project in a single file all of these benefits as mentioned above
- Coordinate the project schedule (4D)
- Estimate the project budget (5D)

When BIM technology is used in the project, a BIM Manager can be also employed or Project Manager should be extra qualified and skilled to ensure the responsibilities of BIM Manager. BIM related activities as utilizing BIM tools are the knowledge area of BIM Manager. The responsibilities are nearly same with Project Manager but BIM Manager has to make extra effort to maintain, implement, manage and coordinate the processes related BIM (Bloomberg, Burney, and Resnick 2012).

It is not sufficient to have technical skills on Project Manager. Strategic and business management and leadership skills also are needed. It is introduced as "PMI Talent Triangle" in the recent PMBOK edition (6th edition) which covers all these skills. In addition to the triple constraints, business alignment, influencing the team, emotional intelligence and performance management understanding must be known (Master of Project Academy 2018).

2.2.6. Collaboration and Communication

BIM enables an integrated model by providing all information in a common model (Merschbrock and Munkvold 2015). On the basis of BIM technology, two main processes gain importance to achieve the success of the project, communication and collaboration. Besides several advantages and benefits, BIM encompasses all stakeholders in a single platform to create more accurate and effective collaboration and communication. All project stakeholders must involve into the project in earlier stages to implement a successful network for collaboration. For this reason, projects based on BIM have superiority than traditional project delivery systems. Figure 2.9 shows the comparison between traditional and BIM process. It can be clearly seen that traditional project delivery system does not contain any relation between project stakeholders (Azhar, Khalfan, and Maqsood 2012). And the information exchange is less common. On the other hand, BIM process exchanges information more accurately and all stakeholders have same detailed information with the aid of collaboration effect of BIM. In addition, to create a collaborative network, technical issues gain importance. Project stakeholders can be used different software to create their model part and integration of these parts can be realized by format exchange as IFC or XML. The detail about format exchange will be clarified in the following sections (Van Berlo and Krijnen 2014).
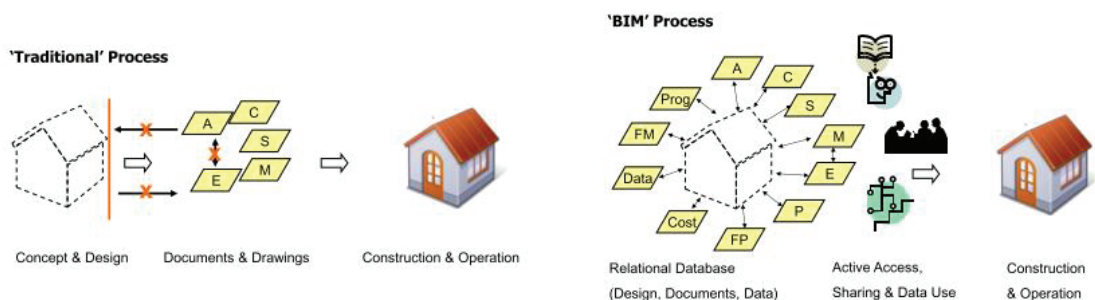

Figure 2.9. Comparison between traditional and BIM process
(Source: Azhar, Khalfan, and Maqsood 2012)

An effective collaboration starts with a regular communication network. Good communication skills provide right information at the right time. An information

management to transfer the knowledge between the project stages must be prepared and the importance must clearly highlight in contract or tender phase (Velasco 2013). The collaboration continues throughout the project life cycle and includes subtasks. First of all, the information management must be identified if an exchange or change has arisen, a notification report must be shared throughout the project stakeholders, change management. Secondly, interoperability must be set and a common format must be agreed by all stakeholders, model exchange. And finally, a control management shall be consolidated by BIM Manager or Project Manager to eliminate the errors and omissions (Tarandi 2015).

A continuous communication can be provided by preparing daily reports, routine meetings and using cloud technology. For example, Autodesk introduced a collaborative add-in and attached to Revit to reach the information whenever the stakeholders want, A360. This cloud system connects and centralizes the model and the stakeholders can reach to BIM project data by using smart phones and tablets (Autodesk 2016) and Figure 2.10 shows communication network of the project which characterized to demonstrate the complexity of a construction project. The first part demand system which creates value for money. The second part is supply system which creates money for value. The key is to create an effective collaboration and value by effective communication skills (Atkin and Borgbrant 2007). The integration of Information Technology (IT) to construction projects improves the quality of the outputs, decreases the cost and concludes the project in time (Brito and Ferreirab 2015).

Government
Stakeholders
Owners
Financiers
Users
Clients

Architects
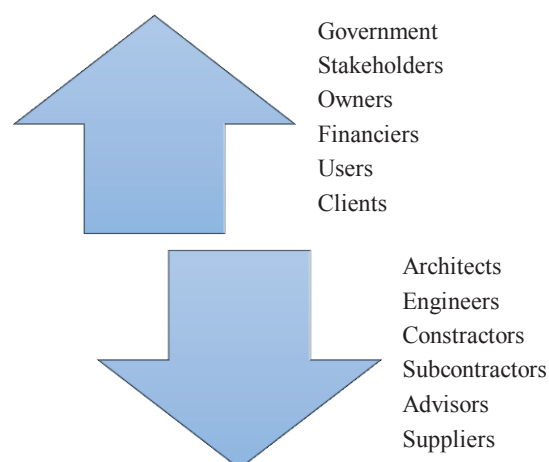Engineers
Constractors
Subcontractors
Advisors
Suppliers

Figure 2.10. Communication network
(Source: Atkin and Borgbrant 2007)

Information flow describes the project development value which is contributed by project stakeholders. Figure 2.11 demonstrates the level of information at each project stage for each project stakeholder. Owner predicts an idea and the communication starts in the design stage between Architect/Engineer (A/E), General Contractor (GC) and Construction Manager (CM) (Brokaw and Mukherjee 2012).
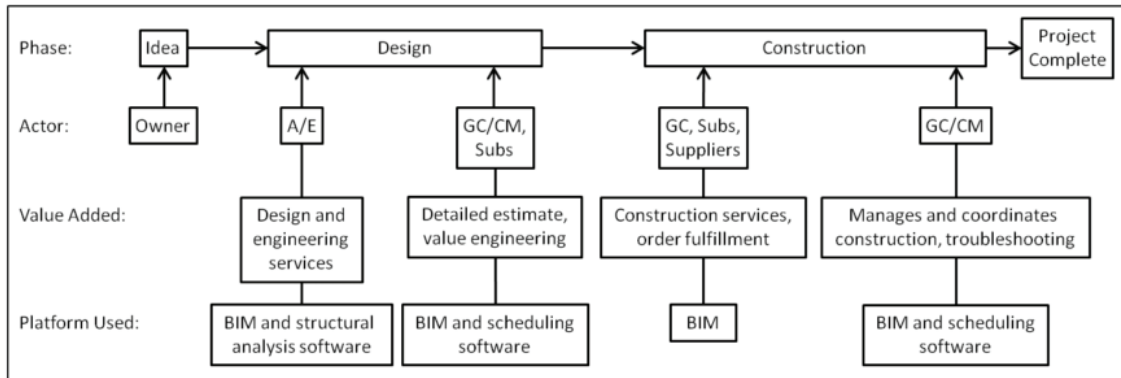
Figure 2.11. Information flow of the project
(Source: Brokaw and Mukherjee 2012)

2.3. Project Management and BIM

The aim of this thesis is to synthesize PM and BIM for construction industry. So here, PM and BIM were considered individually. But now, it must be arranged and considered together in harmony. As mentioned below sections, the goal of a construction project is to complete the construction on time. Due to the complexity of the project stages, lack of collaboration and qualified stakeholders, the project durations generally elongates. For this reason, during the initialization stage of the project, these two methods must be integrated (Tomek and Kalinichuk 2015). Figure 2.12 shows the correspondent knowledge areas of PM and BIM. It can be briefly and clearly seen in Table 2.11 that the knowledge areas are equivalent to each other (Rokooei 2015).
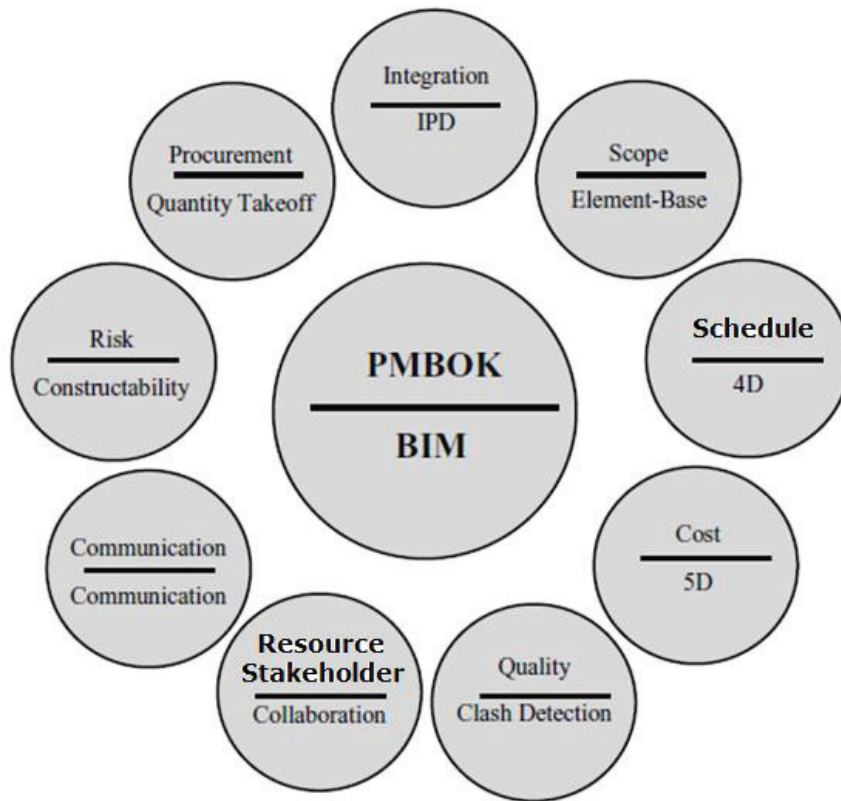
Figure 2.12 PM knowledge areas vs. BIM
(Source: Rokooei 2015)

Basically, three main areas should be examined carefully to integrate PM and BIM processes: (1) parametric modeling, (2) information management and (3) implementation of work (Ghosh, Parrish, and Chasey 2014). This integration determines a solution-oriented approach for project stakeholders (Jones 2014). In addition to 3D model (further information in section 2.3.3), 4D model (further information in section 2.3.6) includes details about scheduling and 5D model (further information in section 2.3.7) estimates the project cost from the model (Bryde, Broquetas, and Volm 2013). 6D model (further information in section 2.3.8) determines sustainability analysis and environmentally evaluation (Gourlis and Kovacic 2016). 7D model (further information in section 2.3.9) has potential benefits for project closeout and called facility management (Bryde, Broquetas, and Volm 2013, Gourlis and Kovacic 2016). The integration of PM and BIM frameworks can be seen in literature as IPD which highlight the theory of effective collaboration and communication practices within a virtual environment (Bryde, Broquetas, and Volm 2013).

Table 2.11. PMBOK knowledge areas vs. BIM descriptions

(Source: Rokooei 2015, Project Management Institute 2017)

PM	BIM	Description	Positive effects
Integration management	IPD	Data handover; documents, elevations, sections, plans...	Improvement
Scope management	Element-based	Categorize the tasks and subtasks	Clarification
Schedule management	4D	Scheduling	Control and Decrease
Cost management	5D	Cost estimation	Control and Decrease
Quality management	Clash detection	Improve the quality by recognizing the clashes	Control and Increase
Resource management	Collaboration	Qualified team members	Improvement
Communication management	Communication	Relationship between the stakeholders	Improvement
Risk management	Risk	Mitigate the risks	Risk reduction
Procurement management	Quantity takeoff	Production of quantity takeoffs	Aid
Stakeholder management	Collaboration	Qualified team members	Improvement

2.3.1. Information Handover - Data Collection

The objective is to store 3D data as documents, technical specifications, drawings and request for information (RFI) into the model. In the past, data collection was made by collecting boxes of information by storing the information into the CD's

by Project Manager. This is called traditional method. Project Manager must scan and eliminate the unnecessary data to collect into the model. However it was very difficult, time consuming and information can be lost during the handover. It can be clearly seen in Figure 2.13 that BIM information line collects better information in every stage of the project with reducing information loss during the handover (Aðalsteinsson 2014).
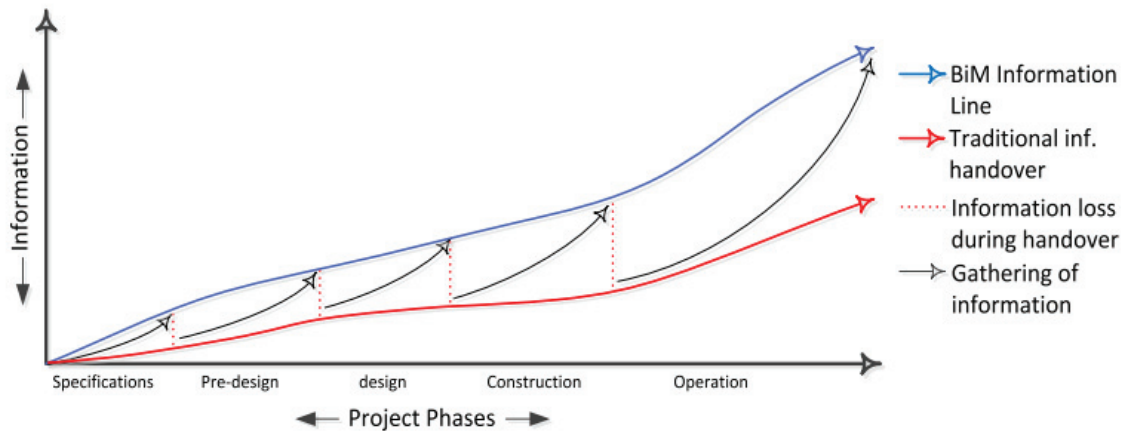
Figure 2.13. Traditional information handover vs. BIM data collection
(Source: Aðalsteinsson 2014)

2.3.2. BIM Interoperability/ Industry Foundation Classes (IFC)

Interoperability is the possibility to flow information from one computer application to the next throughout the lifecycle of a project. Data interoperability is a holistic approach and it is the key factor to improve the PM and BIM efficiency (Pezeshki and Ivari 2016). Lack of technological reasons by using different software creates a problem during the project especially information loss occurs. That is why; a common language between the software has arisen to enhance BIM interoperability.

Industry Foundation Classes (IFC) is emerged by buildingSMART which is a worldwide authority for open and international standards. IFC carries out an exchange between the different software for different stakeholders (Rokooei 2015). It is an open format to transform information between CAD drawing and BIM software by adding the parametric information into the BIM model. By using IFC format, project stakeholders are free to use the software at their own request. It plays an important role

to exchange data and facilitate the way of sharing data (Aðalsteinsson 2014). Figure 2.14 lists the BIM software packages which support data exchange by IFC common schema. Data interoperability is a holistic approach and it is the key factor to improve the PM and BIM efficiency (Rokooei 2015).

IFC is not the only way to exchange the model data between the softwares. All softwares support different file formats as .dwg (Autodesk), .dxf (Autodesk) and .dgn (Bentley) (Aram, Eastman, and Sacks 2013). Green Building XML schema (gbXML) was published by Green Building Studio, Inc to enable interoperability between the BIM software and energy analysis tools (Fallon and Palmer 2007).
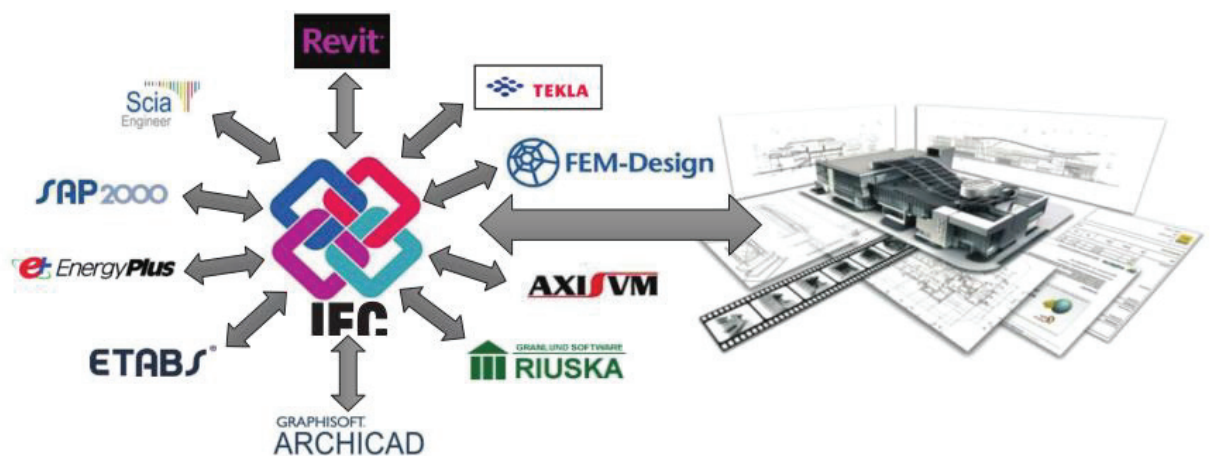
Figure 2.14. IFC and BIM interoperability
(Source: Rokooei 2015)

2.3.3. 3D Modeling

BIM offers high accuracy but only if data is input with the necessary high level of detail into the model. For this reason, the level of detail in the three dimensional (3D) model is a key factor. Material properties, project parameters, family parameters, component properties, unit costs and details about suppliers need to be specified in the model (Aðalsteinsson 2014). 3D models include geometrical (shape and dimension), topological (space), structural and additional information and all non-geometric data

which is called semantic data that cannot be seen in traditional 2D models (Gimenez et al. 2015).

2.3.4. Clash Detection

Clash detection is performed to check the conflicts before the construction. With traditional 2D based workflows, many problems are only discovered at the construction site. BIM based clash detection allows to correct the conflicts before construction starts, by eliminating additional costs and time (Bagdonas 2014). BIM relevant software is able to check and detect the clashes. It means that clash detection tool allows to identify the positions of the two elements which intersect each other (Aziz, Nawawi, and Ariff 2016). Different project disciplines can be checked with clash detection. For example, the clashes between structural system and plumbing can be detected to avoid the conflicts between foundations and pipes (Bagdonas 2014). Table 2.12 summarizes the types of clash can be detected automatically by clash detection.

Table 2.12. Types of clashes
(Source: Bagdonas 2014)

Type of clashes	Function	Example
Hard Clash / Soft Clash	Detection of conflicts between two elements which are in the same position	If a concrete column overlaps above a concrete slab.
Clearance Clash	Clash for inadequate space	If a ventilation pipe cannot install in the ceiling.
Duplicates	The duplication of elements	If a floor is copied inattentively.

Clash detection is the hardest part of BIM project and generally many problems and errors occur. BIM Manager or Project Manager should approach carefully to these errors and must be carefully observed the clash detection reports. Figure 2.15 illustrates a clash detection between structural model and plumbing (Bagdonas 2014).
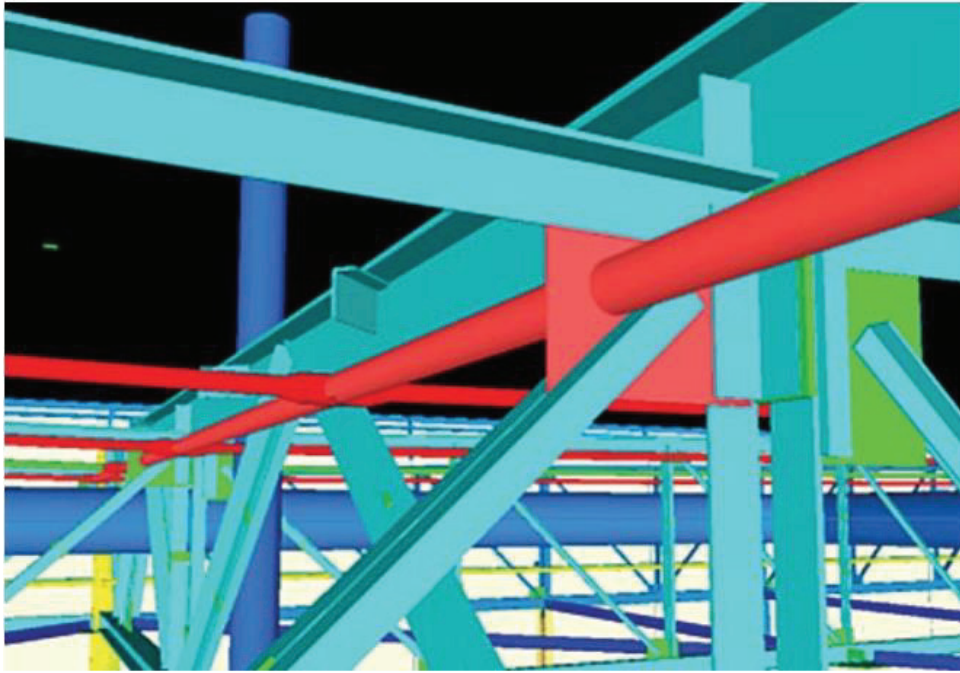
Figure 2.15. Clash detection
(Source: Bagdonas 2014)

2.3.5. Supply Chain / Procurement

Procurement is a process to purchase the required construction goods or service. The parties called as buyer (customer) and seller (subcontractor, vendor or supplier). Supply chain plans the required products or services. The technical product description must be described before the construction to avoid the error of buying wrong product (Project Management Institute 2000).

Time and cost are also the major identifiers of supply chain management. Supply chain management is divided into three parts: (1) activities, (2) components, and (3) associated benefits. Table 2.13 gives briefly details about the subsets of supply chain management. The integration of supply chain management into BIM manages construction site activities and transferring activities (Khalfan 2015).

Before to start the construction, an optimization study must be developed to manage the site logistic and adopts Just in Time (JIT) production and storage as a principle to eliminate waste of transportation time and perform an effective site management. This should be created based on activities to prevent the unnecessary

material at the construction site (Aram, Eastman, and Sacks 2013) and reduce transportation activities based on construction sites (Khalfan 2015). Product based database and price based database must be developed to monitor the procurement activities. These databases should be attached into BIM model (Sciences 2007).

Table 2.13. The subsets of supply chain management
(Source: Khalfan 2015)

Subsets of Supply Chain Management	Theme
Activities	Financial part of activities
	Material flow charts
	Internal and external relationship networks
	Service routine
Components	Purchasing / Procurement
	Fabrication
	Transportation
	Organization
Associated Benefits	Customer satisfaction
	Improvement of efficiency
	Value management

2.3.6. 4D (BIM-based Scheduling)

The fourth dimensional analysis, 4D modeling is an integration of BIM-based scheduling process to plan the construction activities. Scheduling is directly related with activities integrated in time. At planning stage, during the construction or monitoring stages, firms use different scheduling methods. Several of the most common methods are Bar Charts, Gantt Charts or Critical Path Method (CPM). In today's construction world, firms utilize computational tools. There are several programs which produce schedules and reports (Bagdonas, 2014). BIM allows the building components in 3D model and tasks in the schedule to be linked and this creates the 4D model (Tsai et al., 2013). The main advantage of 4D models is the ability they provide to monitor and control the construction more effectively to save time and reduce the total cost. This model also manages resources and logistics of the jobsite (Bagdonas 2014). The

construction simulation from BIM software (e.g. Navisworks) provides an important visualization of the 3D model in time during the construction stage (Brokaw and Mukherjee, 2012). Visualization is enhanced with the change of the color which symbolizes the activity change and creates renders and snapshots (Brito and Ferreirab, 2015). The advantages of 4D models can be summarized in Figure 2.16.
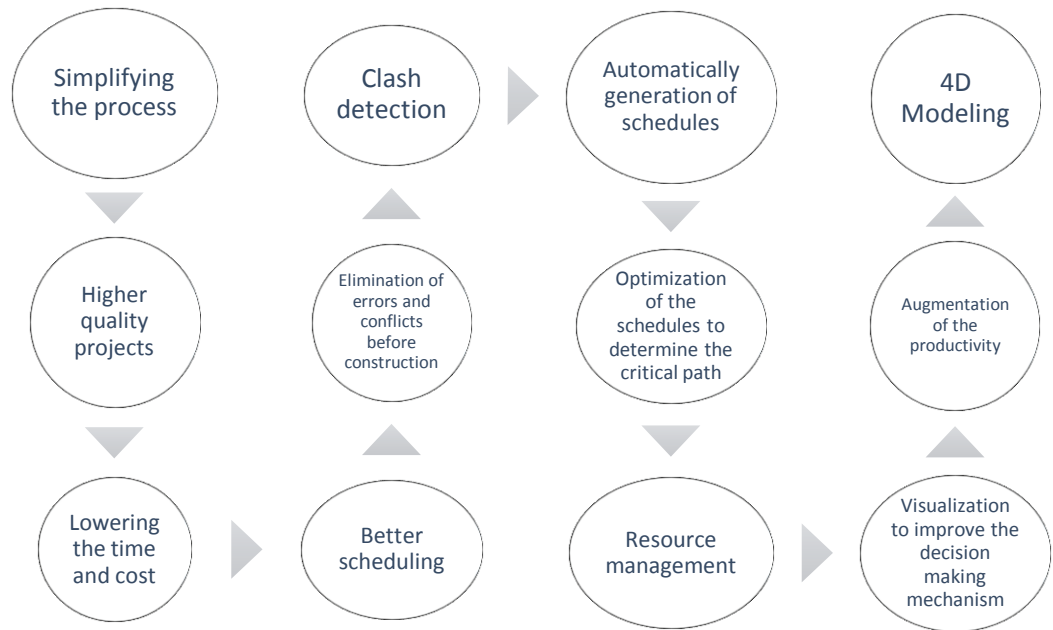
Figure 2.16. The advantages of 4D modeling
(Source: Brito and Ferreirab 2015)

Shortly, it can be said that the difference of 4D beside the 3D model is to link time based activity sequences to generate project schedule and visualize the construction project. A qualified BIM Manager should update 4D schedules with every progress of fabrication to generate the progress reports (Aram, Eastman, and Sacks 2013).

2.3.7. 5D (BIM-based Cost Estimation)

The fifth dimension, 5D model is the integration of cost data into the BIM model (Blažević et al., 2014). Cost estimation is the main financial parameter for construction

projects along with quantity take-off. The important thing to do is to make quantity take-offs and cost estimations in the preliminary design stage. It creates an outlook before the construction starts and if the cost is over budget, the design can be changed and revisions can be made. What is essential is to make these calculations accurately and precisely. Here BIM process is highly advantageous, because detailed calculations are almost immediate savings of time and effort. BIM generates accurate calculations if all required data have been included in the model (Bagdonas, 2014). These estimations are done by giving the unit cost as an input for BIM software for each type of component (Brokaw and Mukherjee, 2012).

2.3.8. 6D (Sustainability)

The rise of environmental consciousness becomes more significant due to the augmentation of energy cost and brought together the importance of sustainability of the construction and eco-friendly building design by minimum environmental destroy. For this reason, governmental organizations create some sustainability and energy requirements as green legislation for the delivery of the projects. BIM models can be performed these analysis in early stages before the commencement of the construction. The required data about the materials and technical statements is already available into the BIM model. The sixth dimension, 6D emerges in here to meet the sustainability requirements. The main benefits of 6D can be given in Table 2.14 below for each project stakeholder (Azhar and Brown 2009).

The main goal of 6D models is the reduction of carbon footprints. Integrating the BIM model with energy analysis tools provides a consideration of energy and carbon targets which is predicted in design stages. Sustainability does not only involve energy analysis but also consists of water preservation, using sustainable materials with reducing material consumption and using recycled materials (Azhar and Brown 2009, Smith 2014).

Sustainability analysis can be called also as performance analysis. The necessary information to make performance analysis obtained from BIM model into the performance analysis software and optimization occurs. The basic information of BIM

model can be considered as building geometry, material information, building system information and internal loads. The interoperability is supported by gbXML data files (Azhar and Brown 2009).

Leadership in Energy and Environmental Design (LEED) is a green building certification developed by U.S. Green Building Council. And it is a rating system for green buildings was established to implement the following topics (Kıncay 2008):

- Create Green Buildings

- Build a common standard

- Recognize environmental leadership in the building industry

- Promote the green competition

- Increase the level of conscious

- Convert the building market strategy to Green Building

Table 2.14. The benefits of 6D

(Source: Azhar and Brown 2009)

Project Stakeholder	The Benefits
Owners	Reduction of sustainability based cost
Architect	Selection of the recycled materials and utilization in the suitable place to decrease the material need Minimize the energy cost (Building orientation) Analysis of the building mass Balance glazing ratios
Engineers	Reduction of energy demands by utilizing renewable energy as solar energy System analysis Daylight analysis Reduction of water demand and use
Contractors	Analysis of environmental site conditions and coordination the site logistics Minimize the energy cost
Subcontractors or Project Managers	Reduction of waste production and carbon footprints

LEED certification is a determining parameter to promote sustainability for green buildings and determines the degree with showing a rating system and has six main rating areas (Jalaei and Jrade 2015):

1. Sustainable site planning

2. Effective use of water

3. Energy efficiency and using renewable energy sources

4. Material and resource selection

5. The quality of indoor environment

6. Innovation and design

If the point is between 40 and 49, the building will be certified that the necessary conditions are fulfilled. If the total point is between 50 and 59, Silver Certification conditions are carried out. If the rating ratio is between 60 and 79, Gold Certification conditions are met. And finally, if the sum is above 80, the building will entitle to receive Platinum Certification (USGBC 2018).

2.3.9. 7D (Facility Management)

The seventh dimension, 7D is an integrated BIM model developed for life - cycle facility management (Wang 2011). The BIM model that is used during construction serves as the as-built model and is passed on to the operation and maintenance phases. McArthur (2015) established four main challenges of facility management with integrating BIM. These challenges are "identify critical information required for sustainable operations", "manage information transfer between the BIM model and other facility management tools", "manage the level of effort to create the model" and "handle uncertainty where building documentation is incomplete". The main key factor is to collect and analyze the data and update the BIM model consistently (McArthur 2015).

2.4. Summary of PM and BIM Integration

Construction industry is constantly growing and improves the processes to reduce the overall cost and to accelerate project completion on time. In addition, other aspects like communication, collaboration and sustainability gain importance. New approaches are continuously emerged but BIM becomes prominent since the 1980's and still continuous with developing day by day (Baker et al. 2012). This method facilitates

the modeling and underlines object-based parametric modeling to collect all data in a data-rich model to be used throughout projects lifecycles (Aðalsteinsson 2014).

Project management and BIM are connected to each other as their purpose is to improve the efficiency by reducing overall cost and saving time. The integration of PM and BIM provides the desired aim with gathering information to a common network which is sharing by all project stakeholders. And also building life cycle management facilitates the information addition, collection, demonstration, visualization and simulation. The technical part, the integration of PM and BIM consists and supports IFC file exchange format to transfer the data from each stakeholder software into BIM model software by project stakeholders (Aðalsteinsson 2014). Table 2.15 is a summary of the PM and BIM systems up to now.

The literature review was explored until here and described the aim of the thesis and presented what can be done to integrate PM and BIM models during the building lifecycle. The next chapter will clarify a case study and the findings will be discussed in the following sections.

Table 2.15. Summary of PM and BIM
(Source: Blažević, Vukomanović, and Radujković 2014)

Project Phases	3D	4D	5D	6D	7D	LOD
Conceptual Design	Information handover	Information handover	Information handover	Information handover	Information handover	LOD100
Schematic Design	Options analysis	Phasing analysis Scheduling analysis	Cost analysis	Investigation of suitable material		LOD200
Detailed Design	3D model Site coordination Constructability analysis	Linking time and scheduling data	Linking cost data	Sustainability analysis Identify potential hazards	Preparation of safety plan	LOD300
Tendering	Tender	Tender	Tender	Tender	Tender	LOD350
Construction Detailing	Shop of drawings	Phasing and scheduling Clash detection Monitor the project progress	Cost estimation Quantity take off preparation	Manage the site Use recycled materials Waste minimization	Maintenance and control the construction	LOD400
Facility Management					Maintenance management Inventory management Real estate portfolio management	LOD500

CHAPTER 3

CASE STUDY

The aim of this thesis is to realize a case study according to the literature review, to conduct an integration between PM and BIM and to see what limitations can occur during the practice. A case study endeavors to design an effective structure in accordance with the design specifications of nD BIM. It should be noted that the case was conducted to give an insight for the applicability of BIM. For this reason, a case study where the BIM model of a three-storey building project is used to carry out various tasks.

3.1. The Methodology

To achieve the goals of this study, a 3D model which includes a data set of quantities, costs and schedules was developed using an integrated suite of tools from a single software company. First, the building was modeled using the BIM authoring system. To conduct Clash Detection for determining the conflicts prior to construction, the model was exported to project review software. BIM-based Scheduling (4D Model) was prepared using a spreadsheet and linked to the project review software to set a Gantt chart. The quantity take-off schedules and cost estimation (5D) were also prepared. Energy analysis was conducted using the authoring system's integrated tools (6D - Sustainability analysis). The effectiveness of BIM approach in terms of Structural Analysis was investigated by linking the BIM system with structural analysis software. To achieve the goals of this study, the project is carried out in phases and the important details of each phase and related software are listed in Table 3.1 which shows the main phases.

Following the methodology, first, the architectural 3D model was developed using Autodesk Revit. The information about the project was stored with the model.

The structural frame created on Floor Plan and 3D model was automatically built. After the creation of architectural columns, floors, walls, stairs, railings, windows, doors and roof; Revit model was linked to Autodesk Robot Structural Analysis (RSA) to perform the structural analysis. The structural 3D Revit model was completed with the addition of foundation and reinforcement details from Robot. To conduct Clash Detection, the Revit model was exported to Navisworks. Work schedule was prepared in Excel and linked to Naviswork to set a Gantt chart. The quantity take-off schedules were prepared automatically in Revit and were exported to Excel. The advantage to import the model using the same company's software is to exchange all data almost without losing any information (Nielsen and Madsen 2010). Figure 3.1 summarizes the case study's BIM flow diagram.

Table 3.1. Project steps

| Project Phase	Detail	Related Software
3D Modeling	Develop a 3D Model which includes a data set of quantities, costs and schedules (Bloomberg et al., 2012).	Autodesk Revit 2018
Clash Detection	To determine the conflicts prior the construction stage (Bloomberg et al., 2012). Check geometrically the design (Fazli et al., 2014)	Autodesk Revit 2018, Autodesk Navisworks 2018
BIM-based Scheduling (4D Model)	Time estimation and visualization of the project according to the schedule (Fazli et al., 2014).	Autodesk Revit 2018, Autodesk Navisworks 2018, Microsoft Excel, MS Project 2018
BIM-based Cost Estimation (5D Model)	Provide a quantity take-off and cost estimation at the design stage. (Bloomberg et al., 2012). Creates financial decisions (Fazli et al., 2014).	Autodesk Revit 2018
Sustainability (6D)	Energy analysis (Fazli et al., 2014).	Autodesk Revit 2018
Facility Management (7D)	Data analysis and collection and BIM model update (McArthur, 2015)	Autodesk Revit 2018
Structural Analysis	Concrete structural framing (Bhusar and Akhare 2014)	Autodesk Robot Structural Analysis Professional 2018
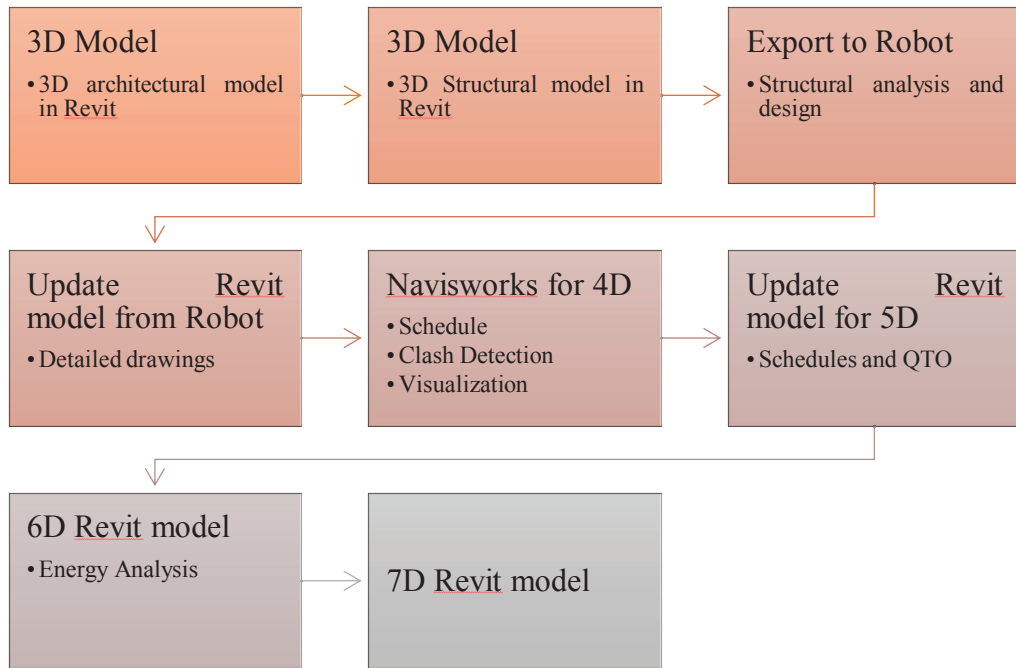
Figure 3.1. Case study flow diagram

(Source: Politi, Aktaş, and İlal 2018)

3.2 Description of the model

To demonstrate how BIM process can be used and its advantages for project management, a case study where the BIM model of a three-storey building project is used to carry out various tasks. The first floor is designed as a commercial area and the other floors are residential areas with two flats in each floor. The building is equipped with curtain and masonry walls with six main rooms and stairs on each floor.

The building is located in İzmir (Turkey) and was designed with a reinforcement concrete structure based on columns, beams and slabs. As for its geometry, the building has a foundation level, a ground floor and three floors, 161 m^2 (16.80 x 9.58 m) floor each area. The story height is 2.80 m. Foundation is constituted by foundation walls and strip foundation. Vertical reinforced concrete columns distributed along the floors and in each floor, 13 columns are situated with 30x60 or 60x30 cm dimension. The concrete class was selected C30/37. Rectangular beam elements were used to support the slab. 30 beams are positioned in each floor with the size of 30x50 and 50x45. Strip foundation with the dimension 200 cm x 100 cm x 70 cm was selected as a foundation. Figure 3.2

shows the first level structural plan view and Figure 3.3 demonstrates the ground level floor plan from Revit software.
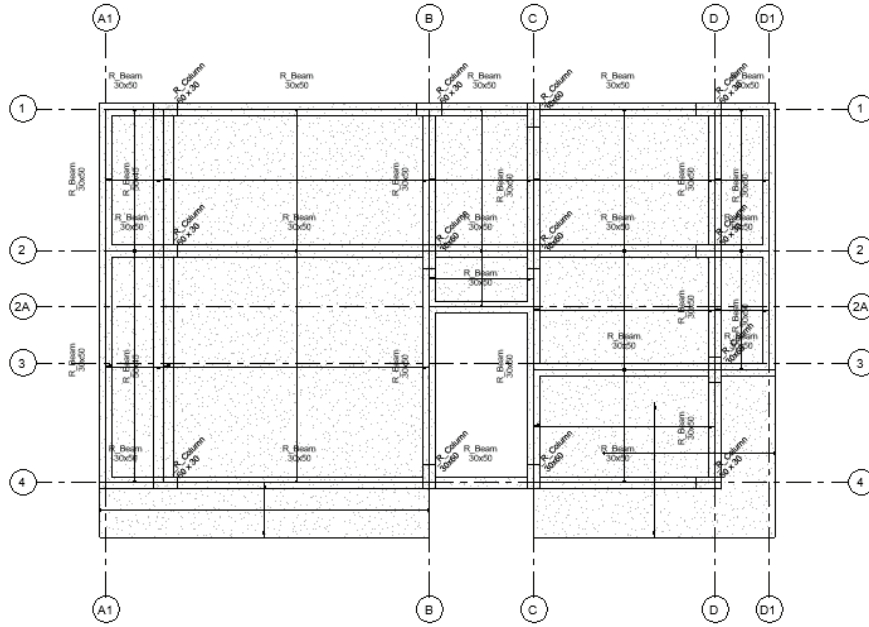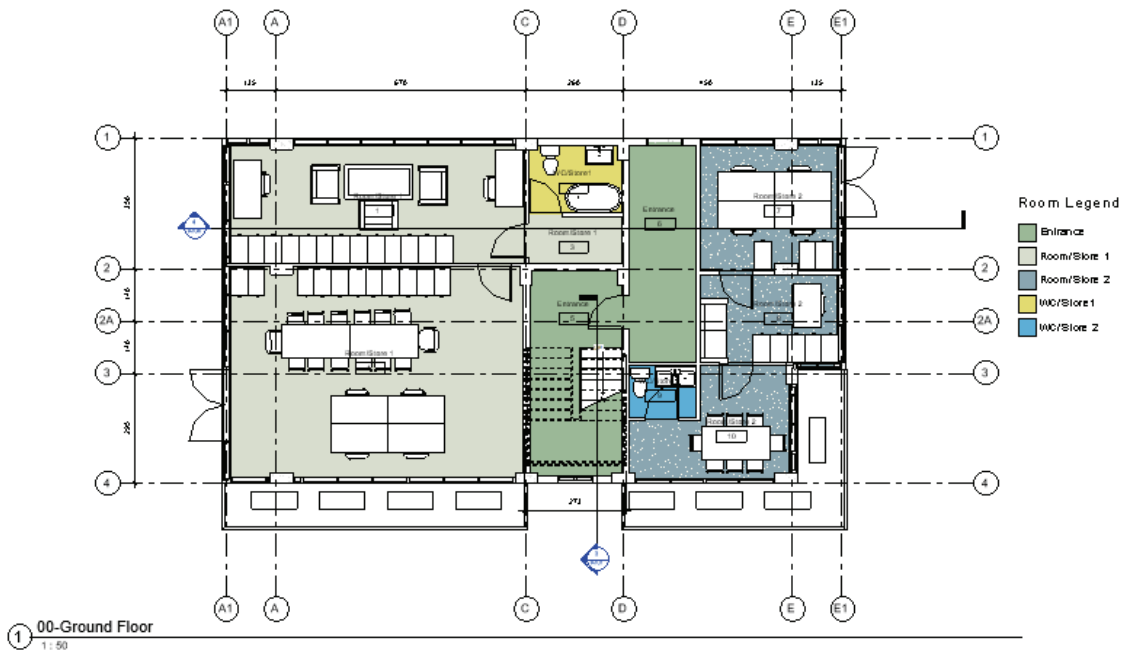

Figure 3.2. First level structural plan view

Figure 3.3.Ground level floor plan

3.3 Project Phases

As described previously, Revit is a database which stores all necessary information about the project. It provides integration between the project management phases and BIM. Revit is developed based on a parametric modeling technology and consists of some parameters. Thus, any change within the project can be adjusted throughout the project. For this reason, parameters have great importance. Parameters store the necessary information and these are the technical properties which can be exported and scheduled to realize the analysis of different discipline (Earley 2013). This software includes hierarchical elements to characterize the Revit components. Components, family, type and instance parameter are the four Revit elements which can be categorized in Figure 3.4. In addition, shared and project parameters also have an importance (Bynum II 2010, Amireddy 2014, Aðalsteinsson 2014, Earley 2013). Table 3.2 summarizes the differences between the Revit parameters.
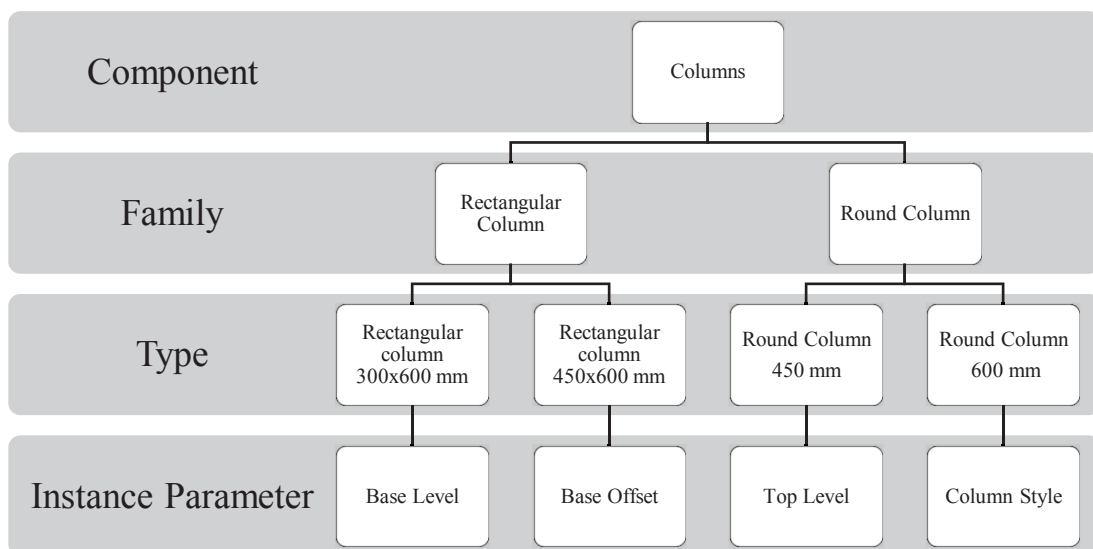
Figure 3.4. Revit parameter hierarchy according to parametric modeling
(Source:(Bynum II 2010, Aðalsteinsson 2014, Amireddy 2014, Earley 2013)

A structural column from the first floor (S103, section 30 x 60 cm and height 2.8 m) element parameters can be seen in Figure 3.5. It can be clearly seen that the family of the column is "M_Concrete-Rectangular-Column"; the type is 60 x 30 cm.

Table 3.2. Revit parameters

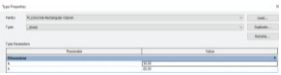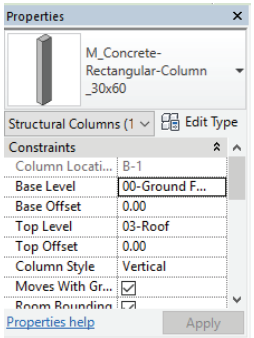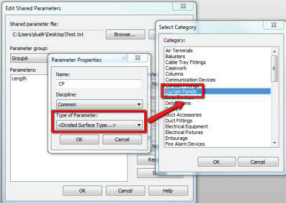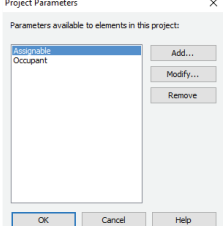| Parameter	Description	
Family Parameter	Components are the smart Revit objects as columns, beams, doors etc (Aðalsteinsson 2014). Each component consists of a family. The main specialty is the controlling purposes of the dimensions and material properties (Autodesk 2015).	
Type Parameter	Type parameters include specific information of the families. The beam type properties which are seen in have a 60 cm of height and 30 cm of width. If any change is occurred in the type properties, the variation can be seen for each common type in the model (Amireddy 2014).	
Instance Parameter	The main difference between instance parameters and type parameter is the modification type. It means that instance parameters can modify property for every instance beside type parameters applies the modification to all family type. For example, base level, base offset, top level, top offset or column style properties are the unique properties and it varies depending on the beam position (Amireddy 2014).	
Shared Parameter	Shared parameters can be created to share the created families with other projects (Amireddy 2014). It facilitates the schedule creation which consists of various family categories (Autodesk 2015).	
Project Parameter	Project parameters are specific properties for a project which cannot be shared. It can be added to elements. It is used to create schedule, to sort and to filter the project (Autodesk 2015, Aðalsteinsson 2014).	
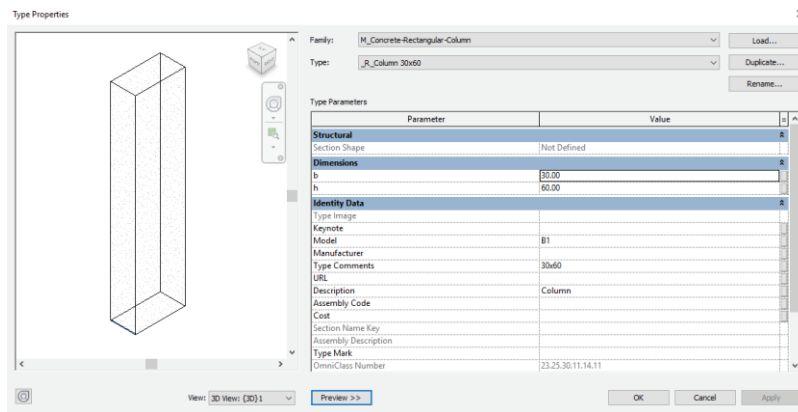
Figure 3.5. Element parameters of a 30 x 60 cm column in Revit Software

3.3.1. 3D Modeling

First part to initiate the project is to prepare architectural 3D model in Autodesk Revit. After the creation architectural columns, floors, walls, stairs, railings, windows, doors and roof; then the structural 3D model is prepared in Revit based on the architectural model.

The second part is to prepare the 3D Structural model in Revit. In this step, structural columns, beams, slabs and foundation are defined respectively. In addition to the architectural BIM model, structural BIM model contains structural element properties, strength parameters, loads, load combinations and boundary conditions. Before the exportation of the model, the analytical and physical model should be verified based on the consistency check and the support conditions are assigned as fixed support. Then the structural model transferred to Robot Structural Analysis to perform the structural analysis for the third part of the case with Robot Structural Analysis Link. The model is send with direct integration.

Figure 3.6 shows the 3D Model of the building in Autodesk Revit. Figure 3.6 is architectural model and Figure 3.7 indicates the structural model.

When the 3D models are created, a shared parameter must be created to facilitate the integration of 4D modeling in Navisworks. A new parameter group should be generated and renamed as "4D Modeling". Within the group, a new parameter must be composed and renamed as "Activity ID for 4D". It must be considered that the type must be selected as text. This shared parameter can also be used in other projects. The

new parameter is stored into Properties bar and the objects should be selected and the Activity ID's must be input according to the schedule, respectively (Baker et al. 2012). Figure 3.8 demonstrates the created parameter in Revit. In this figure, it can be seen the Activity ID of the column highlighted in blue.

Figure 3.6. 3D Architectural Model

Figure 3.7. 3D Structural Model
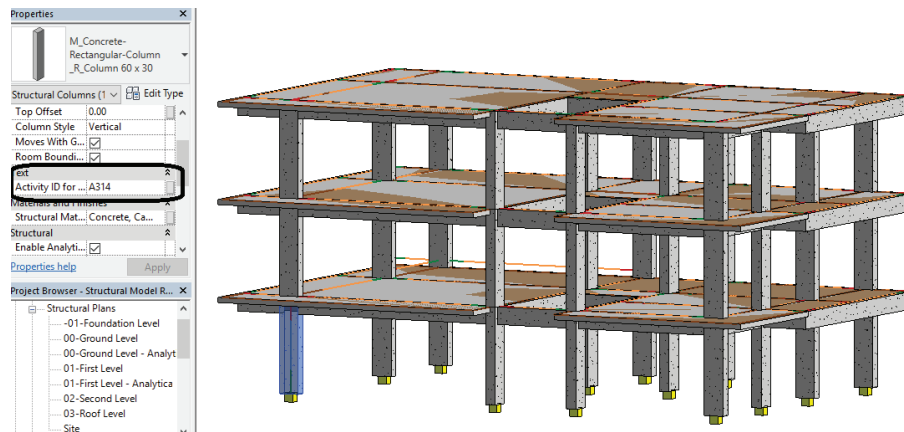
Figure 3.8. The attachment of Activity ID in Revit

3.3.2. Structural Analysis

The third part was to work with the structural model to investigate the interoperability within the software. Within this context, the Revit model was linked to Robot Structural Analysis. Robot's working principle is based on finite element analysis (Major et al. 2017, Nielsen and Madsen 2010). Revit consists of a direct link in analyze tab to export the model to Robot. Revit has two different types to integrate; (1) direct integration, and (2) intermediate smxx file. It is necessary to install both Revit and Robot on the computer for the first type of integration. The second type can be used to exchange the data for different computers. Direct integration is used as a part of this study. Only the structural and the analytical model can be transferred to Robot. For example, if the project contains a multilayered object, only the structural layer can be linked. Table 3.3 summarized the transfer type equivalents of the Revit objects to Robot (Bhusar and Akhare 2014, Autodesk Building Solutions 2016).

During the generation of the 3D Structural Revit model, the pre-sizing of the columns and beams were predicted. According to the Turkish Regulations TS500 (Turkish Standards Institution 2000) and Earthquake Regulations (Bayındırlık ve İskan Bakanlığın 2007), columns and beams were dimensioned. The slab thicknesses were predicted and the floor load patterns were calculated.

The loads can be applied in Revit or Robot. Both options are applicable. Figure 3.9 shows the applied dead and live loads with all the members of the structure. From

the load analysis in Robot, the required forces and moment diagrams were generated to provide the reinforcement of the concrete slab elements and can be seen in Figure 3.10.

All the loads (dead load and live load) applied on the structure were summarized in Table 3.4. The self-weight of the element was defined automatically (Maharjan 2018).
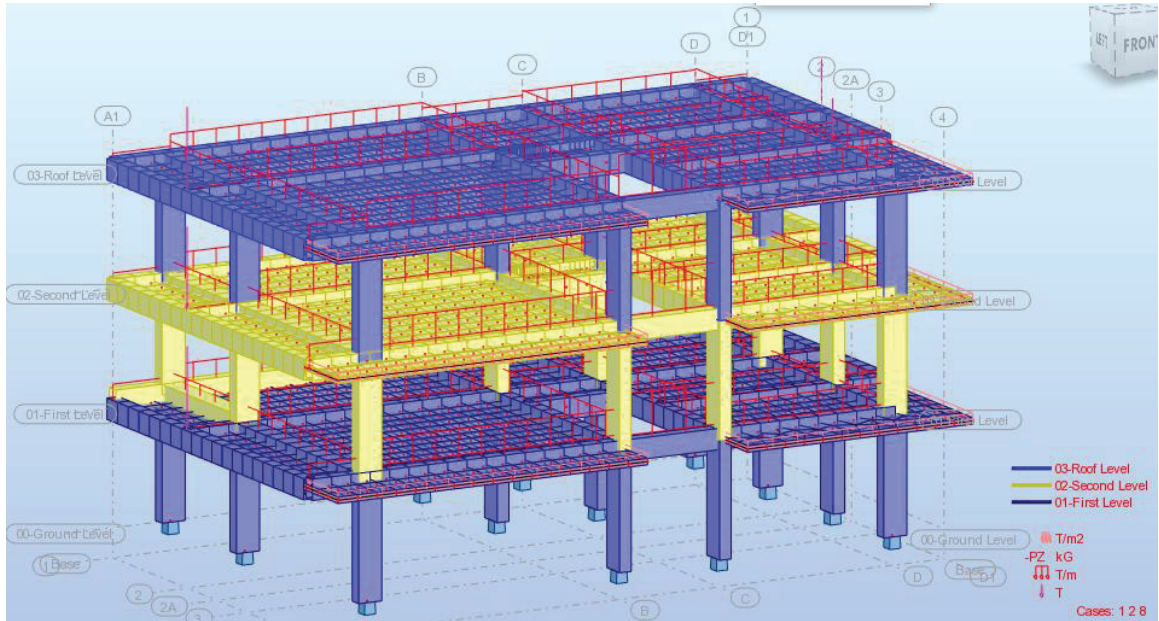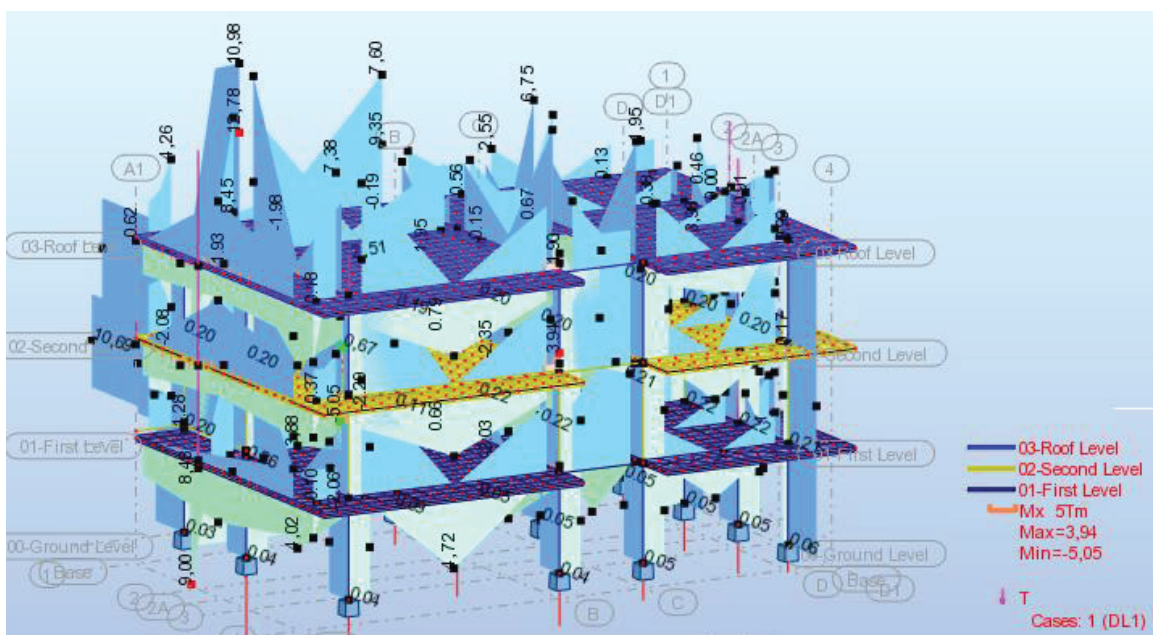

Figure 3.9. Dead and live load application in Robot

Figure 3.10. Moment diagram from Robot

Table 3.3. Transfer methodology between Revit and Robot
(Source: Autodesk Building Solutions 2016)

Revit			Robot	
Revit Element	**Revit Analytical Element**		**Robot**	
Structural column	Analytical column		Column	
Structural framing	Analytical beam		Beam / Bar	
Structural wall	Analytical wall		Wall	
Structural floor	Analytical floor		Floor	
Foundation wall	Analytical wall foundation		Linear support	
Foundation slab	Analytical slab foundation		Floor	
Loads	Loads		Loads	
Boundary conditions	Boundary conditions		Supports	
Materials	Physical assets	Young modulus	Physical assets	E
		Poisson's ratio		NI
		Shear modulus		G
		Density		Re
		Thermal expansion coeff.		LX

Table 3.4. Load description from Robot Structural Analysis

	Case	Load type	List	Load values
	1	self-weight	1to160	PZ Negative Factor=1,00
	1	(FE) uniform	122to160	PZ=-0,54(T/m2) projected
	1	uniform load	38 66 94	PZ=-1,05(T/m) projected
	1	bar force	38 66 94	FZ=-1,90(T) relative
	1	uniform load	39 67 95	PZ=-1,88(T/m) projected
	1	uniform load	40 68 96	PZ=-1,51(T/m) projected
	1	uniform load	41 69 97	PZ=-1,78(T/m) projected
	1	uniform load	42 70 98	PZ=-1,05(T/m) projected
	1	uniform load	51 55 79 83 1	PZ=-0,71(T/m) projected
	1	bar force	51 79 107	FZ=-13,16(T) relative
	1	uniform load	52 80 108	PZ=-2,68(T/m) projected
	1	uniform load	53 81 109	PZ=-1,84(T/m) projected
	1	uniform load	54 82 110	PZ=-2,08(T/m) projected
	1	bar force	55 83 111	FZ=-8,66(T) X=1,00 relative
	1	uniform load	56 84 112	PZ=-2,01(T/m) projected
	1	bar force	56 84 112	FZ=-7,63(T) relative
	1	uniform load	44 72 100	PZ=-1,05(T/m) projected
	1	bar force	44 72 100	FZ=-2,05(T) X=1,00 relative
	1	uniform load	49 77 105	PZ=-1,68(T/m) projected
	1	bar force	49 77 105	FZ=-5,11(T) relative
	1	uniform load	48 76 104	PZ=-2,82(T/m) projected
	1	uniform load	47 75 103	PZ=-3,82(T/m) projected
	1	uniform load	46 74 102	PZ=-2,34(T/m) projected

The dynamic analysis of the structure can be done in Robot. After the period of the structure was found, the earthquake loads acting on the levels were achieved to obtain the shear forces under the horizontal loads. In addition, the superposition of the horizontal and vertical loads is calculated for different load combinations. Figure 3.11 demonstrates the deformation diagram of the building for mode 2.
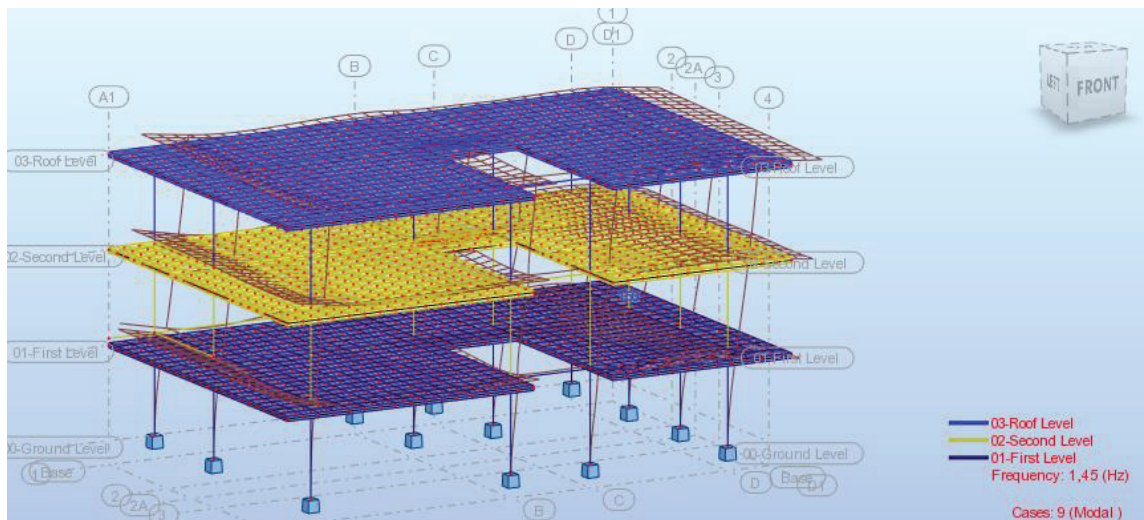
Figure 3.11. Modal analysis deformation diagram for mode 2

It can be produced drawings for each member from Robot Structural Analysis. A single element is selected to get calculation then results and details can be occurred easily. The safety factors were checked for beams and columns according to the load combinations. Reinforcements were generated by Robot. Robot gives information about material properties, geometry, calculation options, loads, calculation results, reinforcement and material survey for columns, beams or foundations. Column reinforcement result of the element provides the normal force versus moment graph to find the maximum column moment which can be seen in Figure 3.12. The normal force and moment values to draw the graph are shown the below the graph. For the reinforcement of the beam, foundation and floor also the same graphs are generated. For all elements; beam, column and foundation, the calculation options, reinforcement pattern, soil definition and geotechnical options can be managed and saved as a preset, so that the same settings can be used in each step. And also it can combine all these data in one sheet. Figure 3.13 demonstrates the reinforcement diagram. Eight pieces of rebar

with a diameter of 18 mm reinforcement were used as a longitudinal reinforcement. The stirrups of diameter 8 were spaced 65 mm near and 140 mm in the middle.
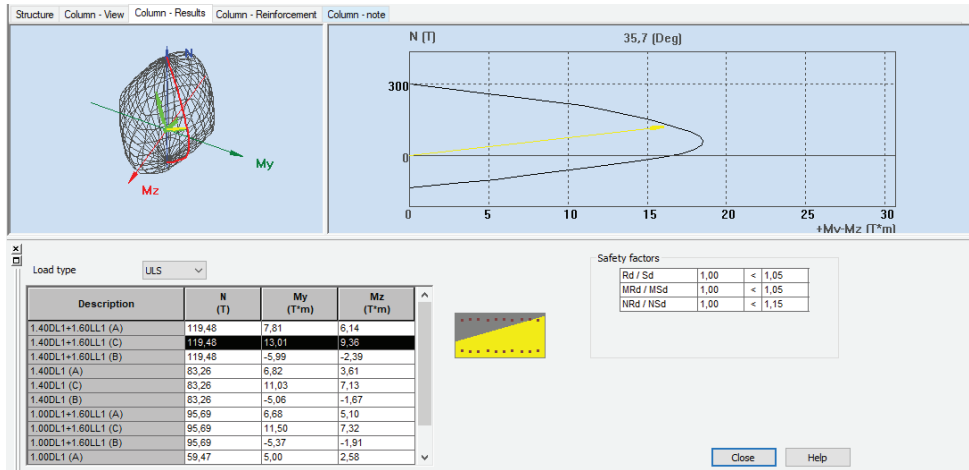
Figure 3.12. Column result from Robot
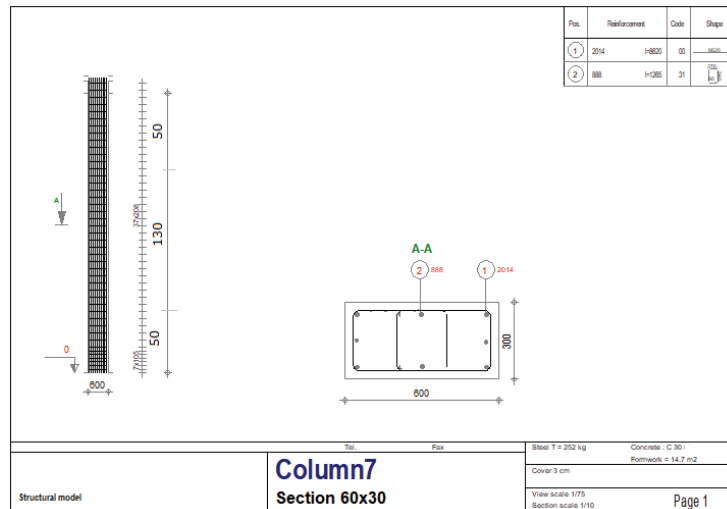
Figure 3.13. Column drawing from Robot

After making the necessary analysis, the model imported to Revit to update the 3D model and to produce structural detailed drawings and to prepare the model to conduct for 4D analysis which can be seen in Figure 3.14. The model is updated in Revit with provided reinforcement for footings, beam and columns from Robot. Figure 3.15 shows a typical output of Robot for column reinforcement. After the

reinforcements process, the Revit model is updated according to the Robot model. Detailed view about structural model as reinforcement visualization can be seen in Figure 3.16.
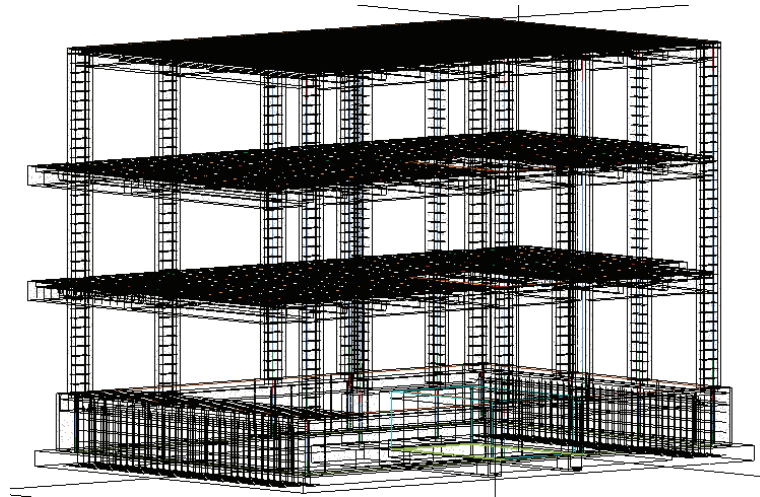
Figure 3.14. 3D Reinforcement in Revit
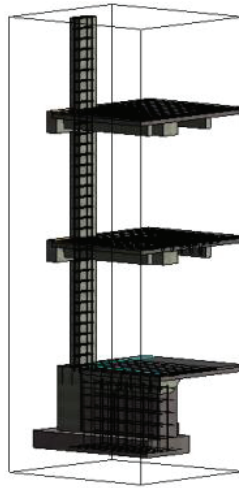
Figure 3.15. Visualization of Reinforcement in Revit

Figure 3.16 summarizes the steps of updating the Robot. The architectural model and structural model were designed. The structural model is exported to Robot Structural Analysis for analysis. And after making the calculations to provide the reinforcement, the structural Revit model was updated.
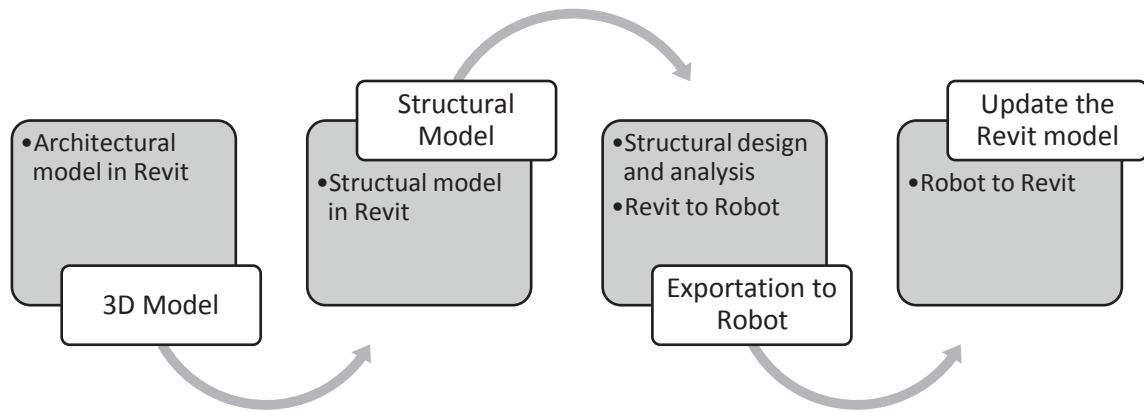
Figure 3.16. Update Revit model from Robot

3.3.3. Clash Detection

To do the clash detection, the 3D architectural model was converted to Navisworks. 4D Analysis is developed by using Autodesk Navisworks which is an integrative software like Revit and it can store different information from different project discipline. The main advantage of 4D models is the ability to provide, monitor and control the schedules related with activities integrated in time. Table 3.5 gives details about Navisworks superiorities.

Navisworks has 3 different products as Navisworks Freedom, Navisworks Simulate and Naviswork Manage. Navisworks Manage was used during this thesis. Navisworks Manage includes all properties for 4D modeling and clash detection on the contrary to Navisworks Simulate which contains only 4D modeling features. The key difference is the "Timeliner" function which allows integration of the schedule and project coordination by clash detection. The other feature that should not be forgotten is the disallowance to modify the model, because it has coordination and visualization opportunity. Another important parameter is the Navisworks file formats descriptions. Navisworks includes three different file formats: (1) NWC (Navisworks Cache File) which is a default format that can be linked to Revit file, (2) NWF (Navisworks File Set) which is a reference file and (3) NWD (Navisworks Document File) which is shared with different project stakeholders. The composite model of Navisworks was

created by exporting Revit to NWC file. Any format change can be realized by opening the model in Navsiworks with save as the model as NWF or NWD (Velasco 2013).

Table 3.5. Navisworks effects on project management

PMBOK Knowledge Areas	Naviswork Superiorities
Integration management	Information integration from different project discipline
Scope management	Visualization of the project
Schedule management	Scheduling and simulation of the construction
Cost management	Realization of the conflicts saves cost
Quality management	Improvement of the quality by clash detection
Resource management	Provide resources and qualified persons
Communication management	Realization of the problem before it occurs and supplying better communication by increasing the information flow with continuously updating the model
Risk management	Realization of the clashes
Procurement management	Realization of the missing materials during the monitoring
Stakeholder management	Realization of the problem before it occurs and supplying better communication by increasing the information flow with continuously updating the model

Revit includes an add-in for exporting the model to Navisworks. Using this add-in, Revit exports the model but some properties are not converted automatically. In Navisworks settings Convert Element Properties check box must be checked to transfer Revit properties into Navisworks properties. In addition, structural model must be saved in .nwc or IFC format. After this process, the architectural model can be opened in Navisworks and the structural model can be appended to the Navisworks model. The main important thing is to align the two models. For this reason, the models are transformed into a composite model. In this step, 4 different file must be ready: (1) Revit Architectural Model, (2) Revit Structural Model, (3) MS Project or Excel Schedule, and (4) Navisworks Composite Model. The last model contains the other 3 models which are exported to Navisworks to create a unique composite model. The schedule is linking to the composite model. The composite model is saved as .nwf file. It links the activity IDs from Revit models (Baker et al. 2012). The aim was to focus on BIM for Structural Engineers. For this reason, the mechanical and electrical models are

not included to this composite model. Figure 3.17 demonstrates the Navisworks composite model.
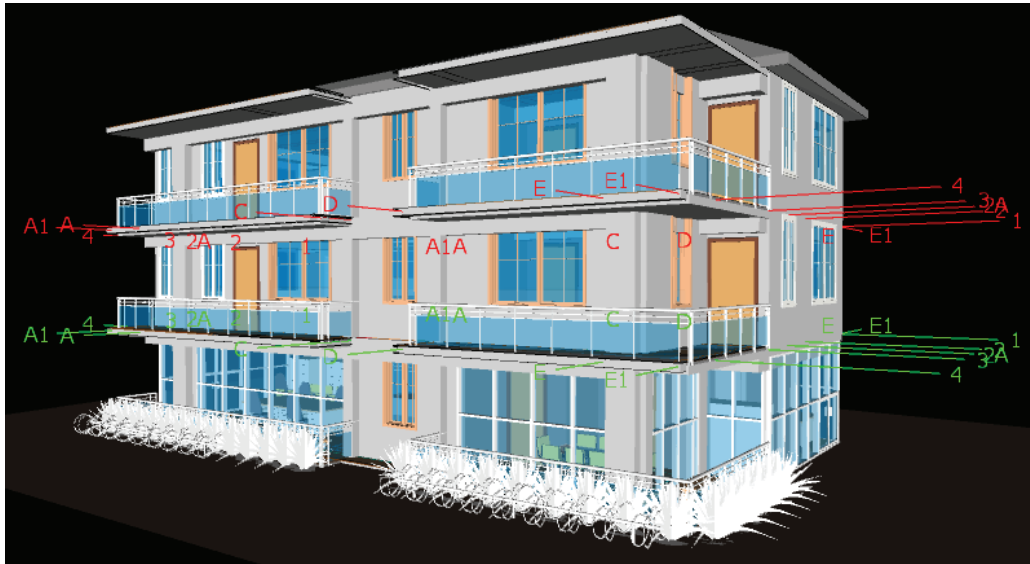
Figure 3.17. Navisworks composite model

BIM based clash detection is done to determine the problems to be corrected before construction starts, with eliminating additional costs and time. To carry out clash detection, "Clash Detective" tool is used. The clashes can be seen in the simulation when the mouse hovers over each clash. All clashes were highlighted according to the color coding. A comment can add over the clash. The model contained 598 clashes. To fix the model, all clash status must be checked as "Approved". Figure 3.18 shows a beam and column intersection.
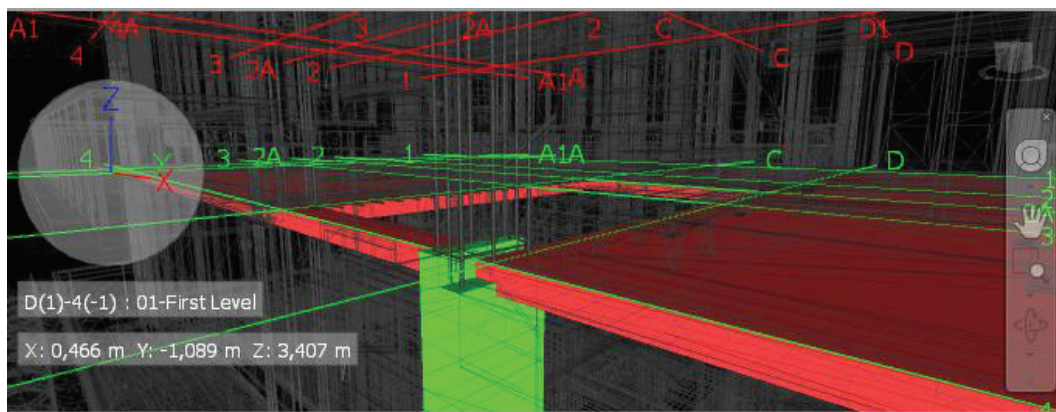
Figure 3.18. Clash detection of a column and floor

After the clash detection findings, these clashes must be fixed in Revit. For this reason, "Switchback" option may be used by selecting the clashing element, the Revit model is opened. The model opens by focusing on the clashing element and it can be quickly fixed (Velasco 2013).

The changes must be saved in Revit and updated in Navisworks. These changes must be done before to link the schedule. Because, every change must be modified in the Navisworks model and it means a reapplication of the linking the schedule and selection sets. Detailed information about what it means will be given in the following section (Velasco 2013).

3.3.4. 4D Modeling

In addition to clash detection analysis, Navisworks includes scheduling, visualization and simulation of the construction project by linking the schedule software within the 3D composite model.

3.3.4.1. Scheduling

A project schedule is a description of the sets activity performed based on a timeline. It is very important to plan all activities on time. It must be specified under the time and money constraint. The essence of the scheduling is to divide the activity into individual parts. Generally, construction projects consists of thousands activities with sequence. The management of thousand activities is very complex to handle. For this reason, computer aided software helps to generate the schedules more accurate. In addition, these programs constitute Gantt chart and determine the critical path automatically. These two methods visualize the schedule to better cope and manage (Baker et al. 2012).

BIM-based Scheduling (4D Model) was prepared using a spreadsheet and linked to the project review software to set a Gantt chart and network diagram. The critical

activities are identified with using CPM. Gantt chart generated automatically as a bar chart by inputting the activities, activity duration times and predecessor for the sequence of the activities (Cherf 2012). The main parameter to classify the project components is the creation of a coding system for Activity ID and these IDs must be corresponding with Revit model element IDs. This was done in Revit by creating a shared parameter.

First of all, activities, Work Breakdown Structure (WBS) milestones and activities were evaluated and the durations were estimated and the schedule was generated by using Excel and MS Project. Excel was used to manage the activities. Activity ID, task name, predecessor, start date, finish date and task type information were installed into the Excel (Velasco 2013). Thus, the schedule was prepared easily with exporting to MS Project.

Gantt chart is created at the earlier stages of a project. The schedules include resources as labor, equipment and material information. CPM demonstrates the activity duration and dependencies. It shows the float for each activity. The important thing is to be known that the critical activity can be delayed without affecting the schedule. It means that it has no lag time. Gantt chart has superiority; it allows graphical representation of the activities. These are the most used project management and control method used (Dave 2013). Figure 3.19 and Figure 3.20 shows small part of the Gantt chart and network diagram which includes detailed information about start date, finish date and duration which are generated in MS Project.
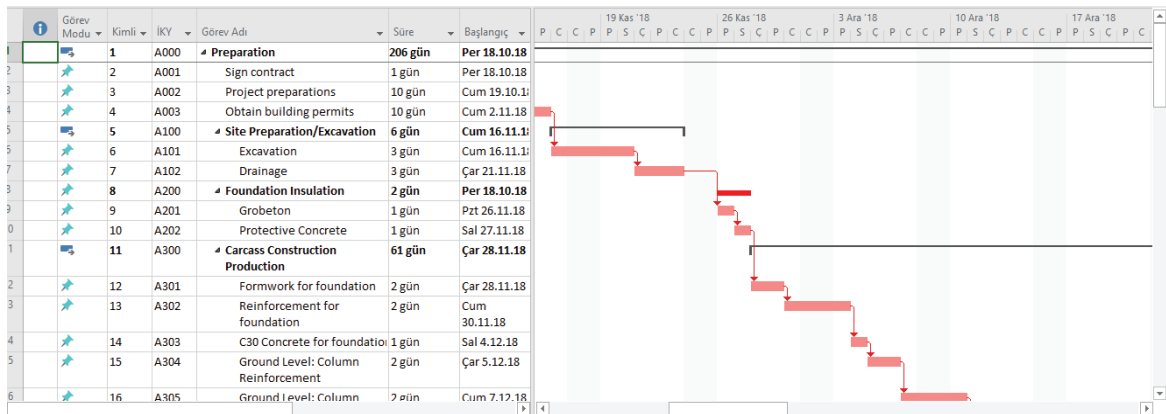
Figure 3.19. Gantt chart
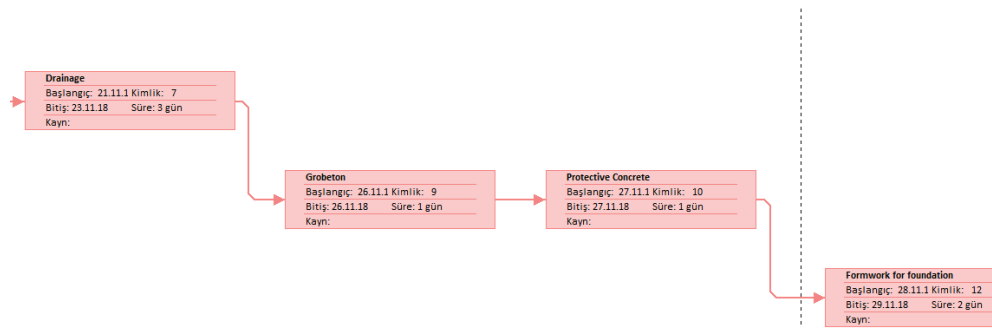
Figure 3.20. Network diagram

The schedule was linked to Navisworks composite model which is used for clash detection. Figure 3.21 summarizes the Navisworks flow. In this step, 3 different file must be ready to create the Navisworks Composite Model: (1) Revit Architectural Model, (2) Revit Structural Model and (3) MS Project schedule.
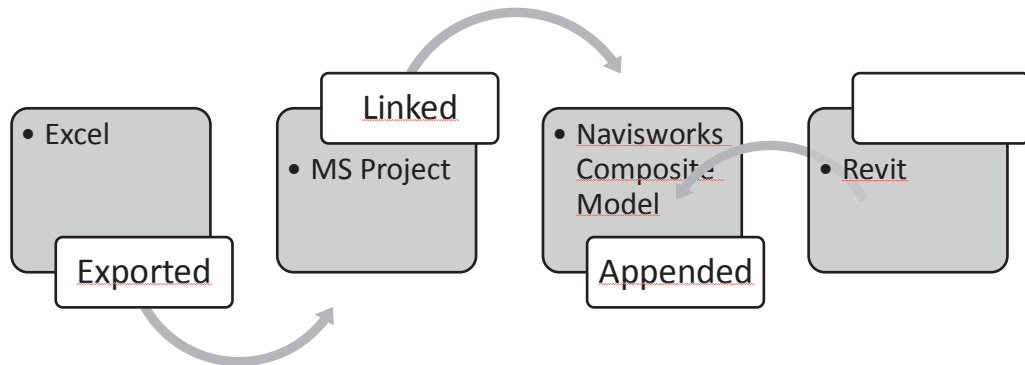
Figure 3.21. Navisworks flow diagram
(Source: Velasco 2013)

In Navisworks, Timeliner is a part where the schedule can be displayed. In this part, the schedule data source was added as MS Project file. If the schedule was linked from Excel, the Excel sheet must be saved as .CSV file to import. The activities and the activity view points were matched into the Navisworks model and 4D model Gantt chart generated. Figure 3.22 shows the 3D composite Navisworks model which includes architectural and structural information with a Gantt chart which is generated by linking the schedule.
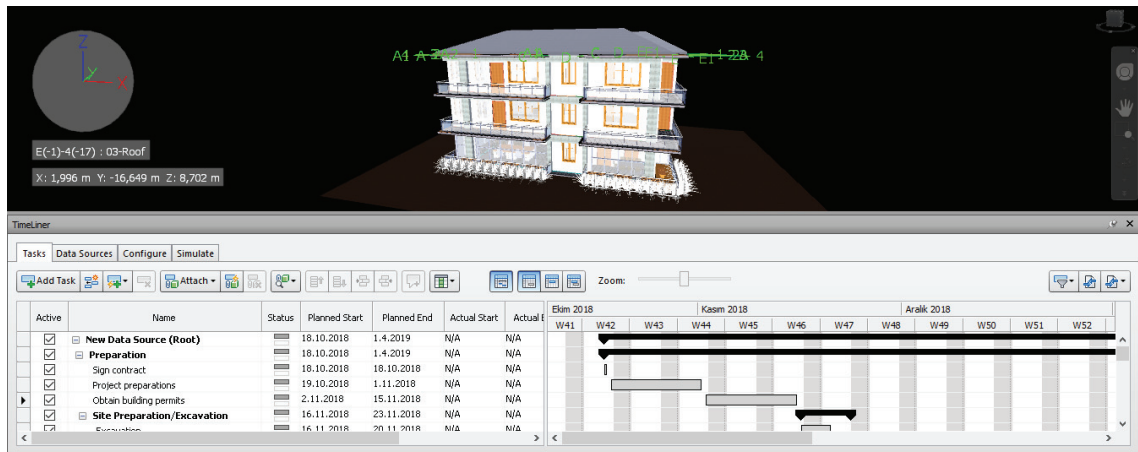
Figure 3.22. 3D Navisworks Model with schedule Gantt chart

3.3.4.2. Simulation and visualization of the construction

Another feature of the 4D modeling is the creation of simulation. This simulation visualizes the increment of the construction and gives pictures and videos about the progress.

Navisworks creates simulation of the construction by importing the BIM model from Revit. A clip or snapshots are created according to the simulation. It reduces the uncertainties and it is used as a communication tool for the coordination of site works. The simulation can be arranged as desired. It can be put forward or backward, or it can be stopped or arranged to desired date on the schedule.

After the linking the schedule into the Navisworks, selection sets preparation is the second point to accelerate the 4D modeling. It facilitates also the visualization and simulation of the construction process by organizing the elements automatically. The purpose is to create a set which contains all of the same individual elements for a selected level or amount of elements links to an activity. Different selection sets can be generated. The set can be named as the correspondent Activity ID which is situated into the schedule and Revit to facilitate the creation of the simulation (Velasco 2013).

Now, the schedule activities and selection sets must be merged and linked. But manually linking method consumes time. For this reason, the activity IDs and selection sets must be named with the same name. Thus, a rule can be created to link the same names automatically and the sets were linked to "Attached" column of the TimeLiner.

67

This column is a part to perform the simulation (Velasco 2013). And also task type must be selected according to the three activity types: construction, demolition and temporary to visualize the site management. For example, a truck or crane is a temporary element and a column is a construction element (Brito and Ferreirab 2015). This is necessary to simulate the project. So, "simulate" tab can be used now to initialize the planned schedule (Baker et al. 2012). Figure 3.23 shows the activities which are occurred in 28th day of the construction. The solid gray objects mean that the element construction is terminated and the transparent green objects mean that the element is under construction.

Navisworks includes two virtual mock-ups as Walkthrough and Flythrough. These functions provide real time navigation by adding an avatar into the visual model to add realism to the model. These features supply to notice any conflicts and decrease the uncertainty. An animation was created by saving the viewpoints.
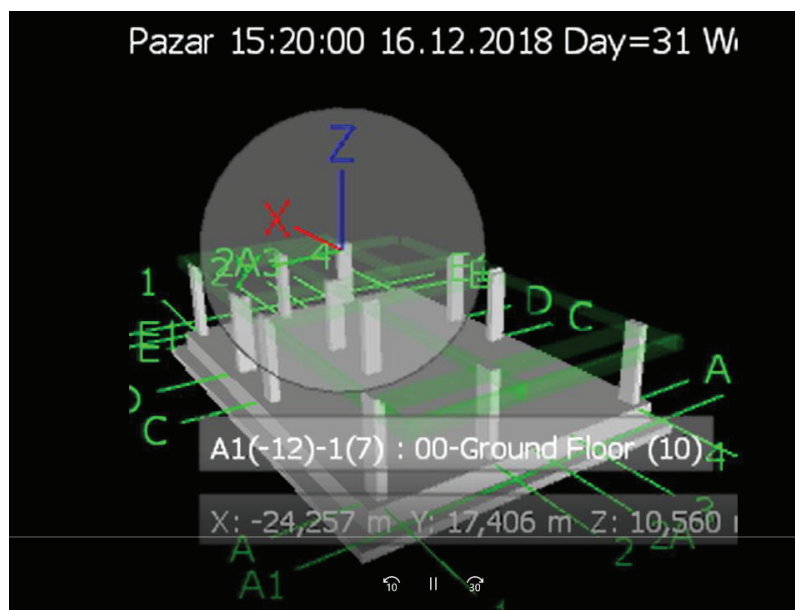
Figure 3.23. Day 31 week 4 simulation

3.3.5. Cost Estimation - 5D

Quantity takeoffs for the construction give an idea and feedback about the way of the construction. It searches answers for how much material is used or what is the cost. That is why generating takeoffs in a timely manner is a big advantage.

The material take-offs of all element materials or some basic materials for example walls, columns or reinforcement can be generated in Revit with "Schedule" panel which is situated in the View tab. With selecting the scheduling fields and sorting them according to the importance level, the schedules and quantities are generated. Beside the prepared scheduling fields, Revit also can estimate "Calculated Values" to identify total cost. Due to the lack of "TL (Turkish Lira)" symbol in currency project unit, a shared parameter is created as a text and named as TL.

To give details, beam material takeoff is prepared and can be seen in Table 3.6. Two types of beam (30x50 and 50x45) with rectangular beam family and type is employed. 30 beams are situated in each floor. The details about first level beams are itemized. For the other levels (ground level and second level) only the total results are given. Every level beam concrete cost is estimated 1644.78 TL. The total beam cost of 90 beam is calculated 4934.36 TL. To estimate the total cost of the project, the bill of materials and quantities must be input. Table 3.7 is the demonstration of Concrete Material Takeoff from the Structural model. The takeoff is prepared automatically. It includes different Revit families and types. It is a summation of how much material is used and what the total cost is. The unit price of concrete, C30 is anticipated a unit price of 140.40 TL/m^3 and multiplied by material volume. The takeoff is sorted by level and type. For foundation, the calculated concrete cost is estimated 11,528.31 TL. Two types of columns are used in the project, 30x60 and 60x30. The first level column and floor concrete cost is estimated 4,269.70 TL. The total concrete material was estimated 32,819.17 TL.

The material quantity takeoffs are generated with using Revit model. The equipment and manpower are gathered in MS Project by assigning the resources to the relevant activity. Table 3.8 shows the project schedule and cost summary. The total cost of the project was estimated to be 543.599,25 TL. This price includes equipment, labor, material and indirect cost. The duration was obtained 206 work days without any delay. The progress of the construction can be tracking by the project % completion on MS Project. This field demonstrates the current status of the task. It is the percentage of the task's duration which has been completed. If the actual date is selected in MS Project, the software gives the %completion rate. Here, the actual date is arranged to 8.1.19, and then the % completion is estimated automatically 21%.

Table 3.6. Beam material takeoff

Structural Framing Schedule							
A	B	C	D	E	F	G	H
Mark	**Type**	**Count**	**Length**	**Volume**	**Unit Price**	**Calculated Cost**	**T.L**
Family: M_Concrete-Rectangular Beam							
Ground Level		30				1644.78 TL	
First Level							
K101	30x50	1	150 cm	0.18 m³	140.40	24.64	TL
K102	30x50	1	655 cm	0.76 m³	140.40	106.51	TL
K103	30x50	1	260 cm	0.27 m³	140.40	38.49	TL
K104	30x50	1	435 cm	0.50 m³	140.40	69.81	TL
K105	30x50	1	150 cm	0.18 m³	140.40	24.64	TL
K106	30x50	1	150 cm	0.11 m³	140.40	15.48	TL
K107	30x50	1	655 cm	0.64 m³	140.40	89.93	TL
K108	30x50	1	260 cm	0.24 m³	140.40	33.91	TL
K109	30x50	1	435 cm	0.41 m³	140.40	57.49	TL
K110	30x50	1	150 cm	0.11 m³	140.40	15.48	TL
K111	30x50	1	260 cm	0.29 m³	140.40	41.17	TL
K112	30x50	1	450 cm	0.44 m³	140.40	61.92	TL
K113	30x50	1	135 cm	0.11 m³	140.40	15.48	TL
K114	30x50	1	150 cm	0.15 m³	140.40	20.38	TL
K115	30x50	1	655 cm	0.64 m³	140.40	89.93	TL
K116	30x50	1	260 cm	0.35 m³	140.40	48.44	TL
K117	30x50	1	450 cm	0.41 m³	140.40	57.49	TL
K118	30x50	1	575 cm	0.73 m³	140.40	102.93	TL
K119	30x50	1	350 cm	0.41 m³	140.40	57.28	TL
K122	30x50	1	575 cm	0.60 m³	140.40	83.82	TL
K123	30x50	1	350 cm	0.34 m³	140.40	47.17	TL
K124	30x50	1	560 cm	0.60 m³	140.40	83.82	TL
K125	30x50	1	350 cm	0.30 m³	140.40	42.75	TL
K126	30x50	1	280 cm	0.25 m³	140.40	34.64	TL
K127	30x50	1	295 cm	0.26 m³	140.40	36.86	TL
K128	30x50	1	350 cm	0.34 m³	140.40	47.17	TL
K129	30x50	1	295 cm	0.37 m³	140.40	52.33	TL
K130	30x50	1	350 cm	0.45 m³	140.40	62.65	TL
K121	50x45	1	350 cm	0.48 m³	140.40	67.39	TL
K120	50x45	1	575 cm	0.82 m³	140.40	114.78	TL
First Level		30				1644.78 TL	
Second Level		30				1644.78 TL	
Grand total: 90		**90**		**35.15 m³**		**4934.36 TL**	

Table 3.7. Concrete material takeoff

			<Concrete Material Takeoff>				
A	B	C	D	E	F	G	H
Description	Type	Mark	Level	Material: Volume	Material: Cost (Unit Price)	Calculated Cost	T.L
Foundation	R_Bearing Footing			41.91 m³	140.40	5,884.16	TL
Foundation Wall	R_Foundation - 10			40.20 m³	140.40	5,644.15	TL
: 16				82.11 m³		11,528.31	
Beam	R_Beam 30x50			31.25 m³	140.40	4,387.85	TL
Beam	R_Beam 50x45			3.89 m³	140.40	546.51	TL
: 90				35.15 m³		4,934.36	
00-Ground Level							
Column	_R_Column 30x60		00-Ground Level	2.90 m³	140.40	406.56	TL
Column	_R_Column 60 x 30		00-Ground Level	3.38 m³	140.40	474.48	TL
Floor	R_Floor 17 cm	D-1	00-Ground Level	25.27 m³	140.40	3,547.38	TL
00-Ground Level: 14				31.54 m³		4,428.43	
01-First Level							
Column	_R_Column 30x60		01-First Level	2.90 m³	140.40	406.56	TL
Column	_R_Column 60 x 30		01-First Level	3.38 m³	140.40	474.48	TL
Floor	R_Floor 15cm		01-First Level	24.14 m³	140.40	3,388.66	TL
01-First Level: 26				30.41 m³		4,269.70	
02-Second Level							
Column	_R_Column 30x60		02-Second Level	2.90 m³	140.40	406.56	TL
Column	_R_Column 60 x 30		02-Second Level	3.38 m³	140.40	474.48	TL
Floor	R_Floor 15cm		02-Second Level	24.14 m³	140.40	3,388.66	TL
02-Second Level: 26				30.41 m³		4,269.70	
03-Roof Level							
Floor	R_Floor 15cm		03-Roof Level	24.14 m³	140.40	3,388.66	TL
03-Roof Level: 13				24.14 m³		3,388.66	
Grand total: 185				233.75 m³		32,819.17	TL

Table 3.8. Project schedule and cost summary

Start	Finish	% Complete	Total Cost	Actual Work	Remaining Work	Total Work Days
Thu 18.10.18	Thu 1.8.19	21%	543.599,25 ₺	30 days	176 days	206 days

3.3.6. Sustainability- 6D

In the fifth step, energy simulation was carried out. Energy analysis is an important part of assessing the performance of the building. It is required that the elements in Revit must contain thermal parameters, lightening, equipment, heating, ventilation and air conditioning system characteristics (Otuh 2016). In architectural model, all elements like walls, slabs or roof are connected to constitute a room. Creating closed spaces is important for the calculation of area and volume. To conduct a proper energy analysis, architectural elements, lighting and equipments (furniture or central heating) must be included. But this thesis only includes architectural and structural model. In the concrete building, there are three types of wall; (1) Exterior wall 20 cm, (2) interior wall (20 cm) and (3) interior wall 10 cm. The basement is designed as a commercial area and glazing is covered. Simulation settings were input, location was set as İzmir for the estimation of weather, and thermal assets, heat transfer coefficient and the layers of the wall were defined. Basic energy model was evaluated. To access the simulation results, "optimize" button in analyze tab is used which is directly opened the Autodesk Insight or attached to the e-mail which is sent by Autodesk that the analysis is completed. On the top of the Insight page which is another software to make environmental performance analysis throughout the building lifecycle, the model visualization can be seen which is shown in Figure 3.24. On the left corner, overall average energy use intensity or annual cost of the model is shown. The mean annual energy cost is calculated as 2.43 USD/m^2/yr. This cost represents the average performance of the design by changing the factor settings. The factors that affect the annual cost can be sorted as window-wall-ratio (WWR), window shades and window glass for each elevation, wall construction, roof construction, infiltration, lighting, daylight and occupancy controls, plug load efficiency, HVAC and photovoltaic system (PV) panels. By clicking to each factor, graphs can be shown. By changing each factor to more airtight or efficiency setting, the energy cost decreases and it shows a higher building performance. On the south wall, the heat gain is predicted 55%, on the north wall; the heat gain is selected 40%. On the western and eastern wall, the heat loss of 30% is specified. By adjusting each factor which affects the project sustainability

performance, the energy cost can be decreased and the building performance will be increased (Aec Learning Gateway 2017).
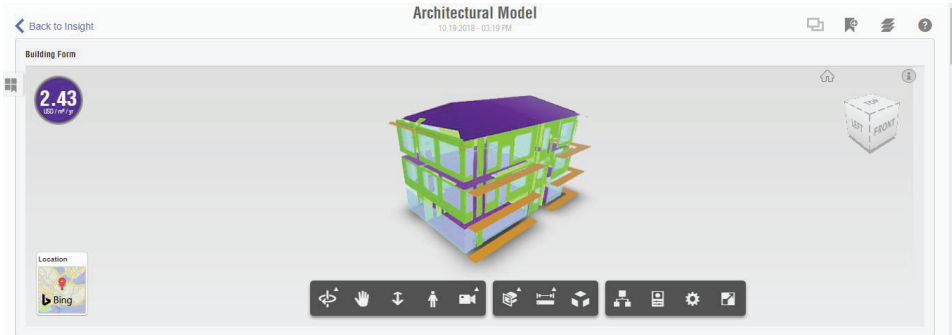

Figure 3.24. 6D analysis Insight report

3.3.7. Facility Management - 7D

The last step was the 7D integrated BIM model developed for life-cycle facility management. The main key factor is to collect and analyze the data and update the BIM model consistently even if the construction is terminated. To collect and analyze the data during and after the construction, new facility management parameters must be created into the BIM model. For example; a construction safety checklist in Figure 3.25 can be prepared. It facilitates the tracking and monitoring of the construction safety processes with storing the information in the same software. This information can be accessed at any time without asking anyone.

<Construction Safety Checklist>		
A	**B**	**C**
Items checked	Checkbox	Comments
Waste materials stores separately	☑	Must be controlled
Work area isolation	☑	
Risk analysis	☑	
All entrances and exits are identified	☑	
Personal protective equipment	☑	
On-site safety and health promotion and continuing information	☑	Organize traning
Environmental control	☑	
General materials handling and storage procedures	☑	
Fire protection equipment	☑	
First aid and helath care medicines, equipment and facilities	☑	
Handling of the hazardous substances	☑	

Figure 3.25. Construction safety checklist

CHAPTER 4

RESULTS AND DISCUSSION

This study presented a BIM-based concept for construction projects to investigate how BIM processes impact project management. For this reason, a three storey building was selected as a case study. The case study demonstrates how BIM allows effective sharing of a 3D model of a project that includes necessary semantic data for all processes that were investigated within the scope of the study. However, it should be noted that generation of the model with all the required information presents challenges for inexperienced users. It can be clearly said that once the model is complete with all details about the model, creating Floor Plans; Ceiling Plans, 3D Views, Perspectives, Elevations, Sections, Renders, Schedules and Quantities can be generated automatically. Furthermore, the ability to detect clashes, errors or defects of the project in the early design stages, before construction, helps managers avoid unnecessary costs.

The aim of this case study was to investigate how project management thinking and BIM could be integrated within a database and the answers were explored during the previous chapters based on literature studies and case study. This project identified different BIM activities as 3D modeling, clash detection, 4D modeling; scheduling, visualization, simulation, 5D modeling; quantity take-offs, cost estimation, 6D modeling, 7D modeling and structural analysis based on construction management. The better way to cope with these uncertainties and circumstances is to prefer BIM models during the construction phase.

BIM facilitates the design and implementation of construction projects and provides a collaborative platform. Several researches show that BIM - based models are time - saving and cost - effective when compared with conventional construction methods. This study provides an insight about how BIM technology can be and will be employed effectively with using different softwares. The benefits of the BIM technology begin at the conceptual design stage and cover the entire lifecycle.

The state-of-the-art of Chapter 2 outlined a literature review about project management requirements and BIM applications. PM methodologies underline the processes that can be followed to achieve the success. By adopting BIM into these methodologies, it emphasis an interaction and make powerful the project manager as knowledge and domination of project. Chapter 3 demonstrated the capability of BIM tools and the validity of the integration between project management functions and BIM according to a case study. To conclude this study, a discussion was conducted to verify if BIM authoring, review and spreadsheet programs were met the requirements of project management. These selected programs demonstrated modeling, clash detection, scheduling, visualization, simulation, estimation, sustainability, management with regard to several analyses. As a result of these functions, some of these corresponded completely and some were not fulfilled exactly. Table 4.1shows the capabilities of BIM to handle with project management knowledge areas.

It can be clearly emphasized that almost all the project management stages and knowledge areas are theoretically and experimentally are totally supported by BIM technology. The "YES" column classification demonstrates the support of the BIM and the "NO" column shows that BIM is not sufficient. Contrary to the traditional project management methods, BIM-based project management facilitates the changes of the project (Velasco 2013).

On the other hand, BIM software applications do not help sufficiently to select qualified project stakeholder or to make risk analysis and assign the resource allocations. And also, it should be noted that generation of the model with all the required information presents challenges for inexperienced users for education and training to learn the BIM software. Even if adopting BIM to a project will increase the cost in the first instance due to the BIM software, education and training costs. But this increase will remain insignificant against the benefits of BIM.

In essence, this case study demonstrated the workflow to adopt BIM technology into the construction projects. Briefly, the underlying theory of BIM is to store and share information throughout the building life cycle and to improve of all the communication, especially communication with owner and work flow of the construction system by combining and tracking in a simple way.

Table 4.1. Comparison table to analyze the opportunities and limitations of project management and BIM

BIM Stages		PM Knowledge Areas	PM Stages	YES	NO	Comments
Decision making	Initializing of the project	Scope management	Initiating	x		Decision making function is fully supported by BIM. It initializes the project and during the project the alteration can be tracked.
3D Modeling	Parametric Modeling	Integration management	Planning	x		3D modeling with BIM authoring system is totally supported by BIM.
Re-planning	Integration	management		x		Update from structural analysis software to BIM authoring system and switchback option in project review software keeps up the information. BIM supports this functionality.
4D Scheduling	Time monitoring	Schdule management		x		Spreadsheet schedules can be exported to review software. BIM totally supports this functionality.
4D Visualization	Visualization	Quality management		x		Planned and Actual schedules are compared according to the colors. BIM totally supports this functionality.
4D Simulation	Coordination of site works	Quality management		x		Simulate option creates different LOD of the projects. BIM totally supports this functionality.
5D Cost Estimation	Cost monitoring	Cost management	Executing - controlling - monitoring	x		BIM authoring system generates automatically the costs if the required price information exists. BIM totally supports this functionality.
5D Quantity Takeoff	Material quantity	Procurement management / Resource management		x		BIM authoring system generates automatically the QTOs. BIM totally supports this functionality.
6D Sustainability	Energy analysis	Quality management		x		Sustainability analysis can be done according to the Energy simulator tool in BIM authoring system. BIM totally supports this functionality.
Qualified staff	Human resource	Resource management			x	BIM authoring system or project review software does not include any HR function. Project management software contains limited capabilities. It helps only for labor not to employ the project stakeholders.

Table 4.1. (cont.)

BIM Stages	PM Knowledge Areas	PM Stages	YES	NO	Comments
Communication of project participants	Communication and interoperability	Communication management / Stakeholder management	x		BIM authoring system is cloud based software. All stakeholders can access to the right information at any time. BIM totally supports this functionality.
Risk analysis	Health and safety management	Risk management		x	Neither BIM authoring system nor project review software includes a risk detection analysis. But the 4D visualization of the project helps to reduce the risks passively.
7D Facility Management	Building management	Integration management — Closing	x		BIM authoring system schedules which are created for 7D can be exported.
Analysis		Quality management — Clash detection	x		Clash detection analysis and real time navigation into the model supports this functionality.
		Site utilization	x		Temporary elements and machinery can be identified in project review software to visualize the site and logistics.
		Site logistics	x		
		Supply chain	x		Supply chain can be managed according to the outlined quantity takeoffs.
		Resource allocation		x	Limited to the capabilities of Project management software. No additional help appears to be included by project review software for resource allocation.
		Structural analysis	x		Structural analysis software has direct integration to BIM authoring system.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter is the final conclusion chapter of this thesis based on the case study results. The benefits and limitations are presented in previous chapters. This part is a total evaluation of BIM-based project management.

5.1 Conclusions

It is very clear to say that BIM has a great potential to streamline the construction by saving the main project constraints as time and cost. It provides a methodology of storage and sharing information between the project stakeholders to create a collaborative network. The aim of this thesis was to clarify how BIM models can be integrated to project management opportunities by using BIM authoring, project management and structural software.

This study demonstrated that BIM authoring systems are useful software applications to cope with the necessities of BIM-based project management for different project stakeholders to coordinate all information in a harmony. By linking the models to each software, different 3D models from different project discipline, material quantity takeoffs with cost estimation, sustainability and structural analysis, a virtual visual model of the construction which is in progress can be prepared. The adoption of BIM is advanced by the smart phone and tablet technology and improves the communication between the stakeholders.

As a closure for this thesis, BIM is an innovative method and continuously developing faster and faster. In fact, the adoption of BIM will be resulted several changes in the construction world. BIM focuses on nD modeling for a better management; in addition to 3D models, 4D modeling proposes a better schedule management, 5D modeling provides a better cost management, 6D modeling supports a

better sustainability management and 7D modeling ensures a better facility management functions by diminishing the project risks and omissions. Furthermore, the quality of the construction will increase by the success of BIM model implementation.

Lastly, construction world is continuously advancing and evolving by technological developments. BIM is not only a technological software innovation but it is also a new way of thinking and knowledge and a combination systematic of several project management areas. At the end, the decision to adopt or discard the BIM innovative technology will be given by the human beings. It can be said that the adoption of BIM is started and the rise will scale up without slowing down.

5.2. Recommendations

To move forward with this study, a more detailed and complex construction would be modeled and the model will be developed with every detail by BIM authoring software. And also, if this model is constructed in real time, it will allow making a comparison in terms of cost and time.

In future, the limitations will be eliminated. The IFC format exchange must be advanced to reduce any data lost.

Further studies can focus on 7D facility management. In the literature, there are insufficient applications on 7D facility management. According to the case, it was found that the utilization of 7D is not adequate and efficient like other nD models.

A framework or guide can be created to necessitate for delivering purposes to governments. Government can provide several BIM conditions as delivering a Revit model or BEP. The boundaries of delivery system must be drawn. An information check list may be prepared during the gathering of information. BEP must be prepared and all the roles and responsibilities must be emphasized. And the scope must clearly define during the earlier stages of the project.

Conducting a case study demonstrated the beneficial parts of BIM-based project management integration. The efficiency of the case will be proved by the realization of the models. The most important change that must be experienced in BIM is the fact that engineers and architects are working simultaneously with a collaborative platform. At

this thesis, all stages were carried out alone. However, the implementation of these processes by a team will bring new coordination and collaboration problems. In this respect, it should be examined in further researches to shed more accurate and integrated technologies throughout the building lifecycle.

It can be hoped that BIM will be worthy and see the deserved value in the Turkish and worldwide construction world because it has an important future in the construction world. The utilization ratio of BIM in the projects will begin to increase over time. Recently, seminars, workshops and conferences began to be organized on this topic. The introductions of this topic to university educational curriculum will emphasis the importance and will move further.

The most important change that must be experienced in BIM is the fact that engineers and architects are working simultaneously with a collaborative platform. However, work together with a team will bring new coordination and collaboration problems. In this respect, it should be examined in further researches to shed more accurate and integrated technologies throughout the building lifecycle.

REFERENCES

Abanda, F. H., B. Kamsu-Foguem, and J. H. M. Tah. 2017. "BIM – New rules of measurement ontology for construction cost estimation." *Engineering Science and Technology, an International Journal* 20 (2):443-459. doi: 10.1016/j.jestch.2017.01.007.

Abanda, F.H., A.H. Oti, and J.H.M. Tah. 2017. "Integrating BIM and new rules of measurement for embodied energy and CO_2 assessment." *Journal of Building Engineering* 12:288-305. doi: 10.1016/j.jobe.2017.06.017.

Abdirad, Hamid. 2015. "Advancing in building information modeling (BIM) contracting-Trends in the AEC/FM industry." AEI 2015: Birth and Life of the Integrated Building, Milwaukee, Wisconsin, March 24-27, 2015.

Abramova, Natalia 2015. "BIM-based design of residential apartment." Double Degree Program in Construction and Civil Engineering Bachelor's thesis, Saimaa University, Lappeenranta, Finland.

Acebes, Fernando, María Pereda, David Poza, Javier Pajares, and José Manuel Galán. 2015. "Stochastic earned value analysis using Monte Carlo simulation and statistical learning techniques." *International Journal of Project Management* 33 (7):1597-1609. doi: 10.1016/j.ijproman.2015.06.012.

Aðalsteinsson, Guðmundur Óskar 2014. "Feasibility study on the application of BIM data for facility management."Master' thesis, Construction Management, Reykjavík University, Reykjavík, Iceland.

Aec Learning Gateway. 2017. 09. Comparing Model and Scenarios.

AIA. 2008. AIA Document E202™-2008. In *Building Information Modeling Protocol Exhibit, Washington, DC: American Institute of Architects*: The American Institute of Architects.

AIA National. 2007. Integrated Project Delivery: A Guide. AIA California Council.

Alizadehsalehi, S., O. Koseoglu, and M. Celikag. 2015. "Integration of building information modeling (BIM) and laser scanning in construction industry." AEI 2015: Birth and Life of the Integrated Building, Milwaukee, Wisconsin, March 24-27.

Amireddy, Shreekanth 2014. "Knowledge Management in Construction using Building Information Modeling (BIM)."Master's thesis, Auburn University, Alabama.

Anderson, Robert 2010. "An introduction to the IPD workflow for vectorworks BIM users." *Nemetschek, Vectorworks*.

Aram, Shiva, Charles Eastman, and Rafael Sacks. 2013. "Requirements for BIM platforms in the concrete reinforcement supply chain." *Automation in Construction* 35:1-17. doi: 10.1016/j.autcon.2013.01.013.

Atkin, Brian , and Jan Borgbrant. 2007. "Development Processes in Construction Management." 4th Nordic Conference on Construction Economics and Organisation, Luleå University of Technology Department of Civil and Environmental Engineering.

Authority, Building and Construction. 2013. BIM Essential Guide for BIM Execution Plan. edited by Building and Construction Authority: Singapor Government.

Autodesk. 2013. Rekabetçi kalmak BIM olmadan ayakta kalabilir misiniz? In *BIM İş Özetleri 04| Rekabetçi Kalmak*: Autodesk.

Autodesk. 2015. About Parameters. *Autodesk Revit 2015 Help*. Accessed September 21, 2016.

Autodesk. 2016. "Autodesk A360 Collaboration for Revit." accessed July 27, 2016. http://www.autodesk.com/products/collaboration-for-revit/overview.

Autodesk Building Solutions. 2016. Revit – Robot interoperability.

Azhar, Salman, and Justin Brown. 2009. "BIM for Sustainability Analyses." *International Journal of Construction Education and Research* 5 (4):276-292. doi: 10.1080/15578770903355657.

Azhar, Salman, Malik Khalfan, and Tayyab Maqsood. 2012. "Building Information Modeling (BIM): Now and Beyond." *Australasian Journal of Construction Economics and Building* 12 (4):15-28.

Aziz, Nor Diana, Abdul Hadi Nawawi, and Nor Rima Muhamad Ariff. 2016. "Building Information Modelling (BIM) in Facilities Management: Opportunities to be Considered by Facility Managers." *Procedia - Social and Behavioral Sciences* 234:353-362. doi: 10.1016/j.sbspro.2016.10.252.

Bagdonas, Petras 2014. "How does BIM influence CDM work flow?" Dissertation Dissertation, Bachelor of Architecture Technology and Construction Management, VIA University College.

Baker, Christopher , Andrew Beliveau, Nica Sylvia, and Machell Williams. 2012. "Construction Management through 5D Building Information Modeling with Alternative Design Considerations."Bachelor's thesis, Worcester Polytechnic Institute, Worcester, USA.

Banaitiene, Nerija, and Audrius Banaitis. 2012. "Risk Management in Construction Projects." In *Risk Management – Current Issues and Challenges*, edited by Nerija Banaitiene, 429-448. intechOpen.com: INTECH Open Access Publisher.

Bayındırlık ve İskan Bakanlığın. 2007. Deprem Bölgelerinde Yapılacak Binalar Hakkında Yönetmelik.

Bhusar, Arpit A. , and Ashish R. Akhare. 2014. "Application of BIM in Structural Engineering." *SSRG International Journal of Civil Engineering* 1 (5):12-20.

Blažević, Gordana, Mladen Vukomanović, and Mladen Radujković. 2014. "Development of a 5D BIM based management system for building construction." Creative Construction Conference 2014, Prag, Češka, 21-24 June.

Bloomberg, Michael R. , David J. Burney, and David Resnick. 2012. BIM Guidelines. New York City Department of Design and Construction.

Brito, Douglas M. , and Emerson A. M. Ferreirab. 2015. "Strategies for representation and analyses of 4D modeling applied to construction project management." *Procedia Economics and Finance* 21:374-382. doi: 10.1016/S2212-5671(15)00189-6.

Brokaw, Christopher, and Amlan Mukherjee. 2012. "Information Integration and Management through the Design and Construction Phases of a Project Life Cycle." Engineering Project Organizations Conference, Rheden, The Netherlands, July 10-12.

Browning, Tyson R. . 2014. "A Quantitative Framework for Managing Project Value, Risk, and Opportunity." *IEEE Transactions on Engineering Management* 61 (4):583-598.

Bryde, David, Martí Broquetas, and Jürgen Marc Volm. 2013. "The project benefits of Building Information Modelling (BIM)." *International Journal of Project Management* 31 (7):971-980. doi: 10.1016/j.ijproman.2012.12.001.

Bynum II, William Patrick 2010. "Building Information Modeling in support of sustainable design and construction."Master's thesis, University of Florida, Florida, USA.

Candelario-Garrido, Alonso, Justo García-Sanz-Calcedo, and Antonio Manuel Reyes Rodríguez. 2017. "A quantitative analysis on the feasibility of 4D Planning Graphic Systems versus Conventional Systems in building projects." *Sustainable Cities and Society* 35:378-384. doi: 10.1016/j.scs.2017.08.024.

Cao, Dongping, Guangbin Wang, Heng Li, Martin Skitmore, Ting Huang, and Weiyu Zhang. 2015. "Practices and effectiveness of building information modelling in construction projects in China." *Automation in Construction* 49:113-122. doi: 10.1016/j.autcon.2014.10.014.

Chen, Shih-Ming, F. H. Griffis, Po-Han Chen, and Luh-Maan Chang. 2013. "A framework for an automated and integrated project scheduling and management system." *Automation in Construction* 35:89-110. doi: 10.1016/j.autcon.2013.04.002.

Cherf, Rick 2012. Lecture 3 - Work Breakdown and Gantt Charts. In *CSTM 462 Planning & Scheduling*. Washington State University, Pullman WA: School of Design and Construction.

Dave, Bhargav 2013. "Developing a construction management system based on lean construction and building information modeling."Doctoral thesis, Salford University, Salford, UK.

Earley, Michael. 2013. Revit Parameters Part 1 - Concepts. BIM Manager Notes from the field.

Eastman, Chuck, Paul Teicholz, Rafael Sacks, and Kathleen Liston. 2008. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*. 1st ed. New Jersey: John Wiley & Sons Inc.

Elmualim, Abbas, and Jonathan Gilder. 2013. "BIM: innovation in design management, influence and challenges of implementation." *Architectural Engineering and Design Management* 10 (3-4):183-199. doi: 10.1080/17452007.2013.821399.

Erdoğan, Fidan. 2009. "Türk inşaat sektöründe 4D-CAD uygulamalarının değerlendirilmesi ve uygulama örneği."Master's thesis, Civil Engineering, Istanbul Technical University, Istanbul, Turkey.

Fallon, Kristine K. , and Mark E. Palmer. 2007. General Buildings Information Handover Guide: Principles, Methodology and Case Studies.

Fleming, Wojciech Stanisław. 2016. "BIM modelling for structural analysis."Master's thesis, Structural Engineering, Poznan University of Technology, Poznan, Poland.

Garel, Gilles 2013. "A history of project management models: From pre models to the standard models." *International Journal of Project Management* 31:663-669. doi: 10.1016/j.ijproman.2012.12.011.

Ghosh, Arundhati, Kristen Parrish, and Allan D. Chasey. 2014. "Implementing a Vertically Integrated BIM Curriculum in an Undergraduate Construction Management Program." *International Journal of Construction Education and Research* 11 (2):121-139. doi: 10.1080/15578771.2014.965396.

Gimenez, Lucile, Jean-Laurent Hippolyte, Sylvain Robert, Frédéric Suard, and Khaldoun Zreik. 2015. "Review: reconstruction of 3D building information models from 2D scanned plans." *Journal of Building Engineering* 2:24-35. doi: 10.1016/j.jobe.2015.04.002.

Gourlis, Georgios, and Iva Kovacic. 2016. "Building Information Modelling for analysis of energy efficient industrial buildings – A case study." *Renewable and Sustainable Energy Reviews*. doi: 10.1016/j.rser.2016.02.009.

Grover, D. . 2002. Graphical Project Planning Techniques: An Overview of Gantt, PERT, and CPM Charts. Accessed July 12, 2016.

Hillier, F. S. , and G. J. Lieberman. 2001. *Introduction to Operations Research*. 7 ed: McGraw-Hill.

Hughes, Daniel 2013. McGraw-Hill Lean Construction-BIM Report. Bradley BIM-Revit Resource Portal: Bradley Corp.

Jalaei, Farzad, and Ahmad Jrade. 2015. "Integrating building information modeling (BIM) and LEED system at the conceptual design stage of sustainable buildings." *Sustainable Cities and Society* 18:95-107. doi: 10.1016/j.scs.2015.06.007.

Jankowski, Bartosz, Jakub Prokocki, and Michał Krzemiński. 2015. "Functional Assessment of BIM Methodology Based on Implementation in Design and Construction Company." *Procedia Engineering* 111:351-355. doi: 10.1016/j.proeng.2015.07.100.

Jones, Barry. 2014. "Integrated Project Delivery (IPD) for Maximizing Design and Construction Considerations Regarding Sustainability." *Procedia Engineering* 95:528-538. doi: 10.1016/j.proeng.2014.12.214.

Khalfan, M. 2015. "Building Information Model and Supply Chain Integration: A Review." *Journal of Economics, Business and Management* 3 (9). doi: 10.7763/joebm.2015.v3.308.

Kıncay, Olcay 2008. ""Yeşil" Binalarda LEED Sertifikası." *Yıldız Technical University Renewable Energy Systems Lecture Note*.

Level, Cambridge International AS and A. 2015. "Topic 4.4.3 Project management PERT and GANTT charts." In *Topic support guide*: Cambridge International AS and A Level Computer Science.

Maharjan, Ardeep 2018. "Structural Analysis of an Office Building with Robot Structural Analysis and Manual Calculation."Bachelor's thesis, Construction Engineering, HAMK University of Applied Sciences.

Major, Maciej , Izabela Minda, Krzysztof Kuliński, and Izabela Major. 2017. "Comparative numerical analysis of obtained stress and displacement results fromFEM programs - robot structural analysis and Adina in example of a steel footbridge subjected to the dead load." *Transactions of the VŠB – Technical University of Ostrava Civil Engineering Series* 17 (2):51-58.

Maserang, Sean. 2002. Project Management: Tools & Techniques.

Master of Project Academy. 2018. PMP 2019 - 7 Key Changes in PMBOK 6th Edition.

McArthur, J. J. 2015. "A Building Information Management (BIM) Framework and Supporting Case Study for Existing Building Operations, Maintenance and Sustainability." *Procedia Engineering* 118:1104-1111. doi: 10.1016/j.proeng.2015.08.450.

Merschbrock, Christoph, and Bjørn Erik Munkvold. 2015. "Effective digital collaboration in the construction industry – A case study of BIM deployment in a hospital construction project." *Computers in Industry* 73:1-7. doi: 10.1016/j.compind.2015.07.003.

Messner, John I., Chimay J. Anumba, Craig R. Dubler, and Nevena Zikic. 2010. *BIM Project Execution Planning Guide*. The Pennsylvania State University: Computer Integrated Construction Research Program, The Pennsylvania State University. Guide.

Mihic, Matej, Josip Sertic, and Ivica Zavrski. 2014. "Integrated Project Delivery as Integration between Solution Development and Solution Implementation." *Procedia - Social and Behavioral Sciences* 119:557-565. doi: 10.1016/j.sbspro.2014.03.062.

Nielsen, Anne Kathrine , and Søren Madsen. 2010. "Structural modelling and analysis using BIM tools."Master's thesis, Civil Engineering, Aalborg University, Aalborg

Otuh, Nnanna Francis 2016. "BIM Based Energy/Sustainability Analysis for Educational Buildings – A Case Study."Bachelor's thesis, Construction Engineering, HAMK University

Pezeshki, Zahra, and Syed Ali Soleimani Ivari. 2016. "Applications of BIM: A Brief Review and Future Outline." *Archives of Computational Methods in Engineering* 25 (2):273-312. doi: 10.1007/s11831-016-9204-1.

Politi, Ruti R. , Engin Aktaş, and M. Emre İlal. 2018. "Project Planning and Management Using Building Information Modeling (BIM)." 13th International Congress on Advances in Civil Engineering (ACE2018), Çeşme, İzmir - Turkey, 12-14 September 2018.

Project Management Institute. 2000. *A guide to the project management body of knowledge (PMBOK® Guide)*. Edited by Project Management Institute. 2000 ed, *PMBOK® Guide*. Newtown Square, Pa: Project Management Institute.

Project Management Institute. 2017. *A guide to the project management body of knowledge (PMBOK® Guide)*. Edited by Project Management Institute. 6th Edition ed, *PMBOK® Guide*. Newtown Square, Pa: Project Management Institute.

Quirk, Vanessa. 2012. A Brief History of BIM. Accessed 11.2.2016.

Radujković, Mladen, and Mariela Sjekavica. 2017. "Project Management Success Factors." *Procedia Engineering* 196:607-615. doi: 10.1016/j.proeng.2017.08.048.

Rokooei, Saeed. 2015. "Building Information Modeling in Project Management: Necessities, Challenges and Outcomes." *Procedia - Social and Behavioral Sciences* 210:87-95. doi: 10.1016/j.sbspro.2015.11.332.

Rumane, Abdul Razzak 2017. *Handbook of Construction Management: Scope, Schedule, and Cost Control, Industrial innovation series*: CRC Press Taylor&Francis Group Boca Raton, FL.

Sciences, National Institute of Building. 2007. United States National Building Information Modeling Standard. In *Version 1 - Part 1 : Overview, Principles and Methodologies*: National Institute of Building Sciences.

Smith, Peter 2014. "BIM & the 5D Project Cost Manager." *Procedia - Social and Behavioral Sciences* 119:475 – 484. doi: 10.1016/j.sbspro.2014.03.053.

Tarandi, Väino. 2015. "A BIM Collaboration Lab for Improved through Life Support." *Procedia Economics and Finance* 21:383-390. doi: 10.1016/s2212-5671(15)00190-2.

Tomek, Radan, and Sergey Kalinichuk. 2015. "Agile PM and BIM: A Hybrid Scheduling Approach for a Technological Construction Project." *Procedia Engineering* 123:557-564. doi: 10.1016/j.proeng.2015.10.108.

Turkish Standards Institution. 2000. TS500 Requirements for Design and Construction of Reinforced Concrete Structures.

USGBC. 2018. "LEED is green building." Last Modified November 10, 2018. https://new.usgbc.org/leed.

Van Berlo, Léon, and Thomas Krijnen. 2014. "Using the BIM Collaboration Format in a Server Based Workflow." *Procedia Environmental Sciences* 22:325-332. doi: 10.1016/j.proenv.2014.11.031.

Velasco, Alberto Urbina. 2013. "Assessment of 4D BIM applications for project management functions."Master's thesis, European Master in Construction Engineering, University of Cantabria, Cantabria, Spain.

Wang, Menglin 2011. "Building Information Modeling (BIM): Site-Building Interoperability."Master's thesis, Interdisciplinary Construction Project Management, Worcester Polytechnic Institute, Worcester, USA.

Winston, Wayne L., and Jeffrey B. Goldberg. 2004. *Operations Research: Applications and Algorithms*. 4th ed. Belmont, CA: Thomson/Brooks/Cole.