An Investigation on Some Benefits of BIM Application

Aliye Dalcı

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of

Master of Science
in
Civil Engineering

Eastern Mediterranean University
August 2014
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Elvan Yılmaz
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Civil Engineering.

Prof. Dr. Özgür Eren
Chair, Department of Civil Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Civil Engineering.

Prof. Dr. Tahir Çelik
Supervisor

Examining Committee

1. Prof. Dr. Tahir Çelik
2. Assoc. Prof. Dr. İbrahim Yitmen
3. Asst. Prof. Dr. Serhan Şensoy

ABSTRACT

Building Information Modeling (BIM) is a new technology in construction industry. It uses real-time models to increase efficiency and productivity in construction projects. With the help of this technology, projects can be completed on time and within budget. Client satisfaction is increased because the clients know what will be the end product during the design stage. Reworks can also be minimized due to better understanding of project and visualization ability.

This thesis is on the efficiency of BIM on project drawings and bill of quantity calculations. One of the BIM software, named Autodesk Revit Architecture and traditional way, AutoCAD were used in this thesis to produce project drawings. An apartment building project was selected to prepare project drawings by using both AutoCAD and Autodesk Revit Architecture and the efficiency of both softwares in terms of the duration of producing project drawings were compared.

Also the possibility of preparing more accurate and fast architectural bill of quantities by Autodesk Revit Architecture and Autodesk Quantity Takeoff were compared with manually obtained bill of quantity calculations.

In addition, in this study, two surveys were conducted. One of the surveys was an interview related with the advantages and disadvantages of AutoCAD and Autodesk Revit Architecture with four architects who prepared project drawings. The second survey was a questionnaire conducted with twenty construction companies in North

Cyprus. The aim of this survey was to determine the extension of duration factors and rework factors during the whole construction project.

The conclusions which were developed in this thesis are that BIM should be used in North Cyprus to produce fast project drawings and to obtain more accurate and fast bill of quantities. Changing the demands of clients is one of the most important reasons for both extension of duration and increase of reworks in construction projects. Changing demands can be minimized by using BIM and 3D visualization at the early stages of projects for better understanding of the projects by the clients. So, it contributes to the projects to be finished on time without leading to extra costs for reworks in the construction stage of projects.

Keywords: Building Information Modeling, quantity takeoff, rework, on time completion

ÖZ

Yapı Bilgi Modellemesi (BIM), inşaat sektöründe kullanılan yeni bir teknolojidir. BIM gerçek zamanlı modeller kullanarak inşaat projelerindeki verimliliğin artmasına yardımcı olur.Yapı Bilgi Modellemesinin birçok faydası vardır. Bu teknoloji ile projeler bütçeyi aşmadan zamanında tamamlanabilir ve müşteri memnuniyeti artırılabilir çünkü müşteri en başta ilerde nasıl bir projenin inşa edileceğini üç boyutlu modeller sayesinde görebilir ve proje süresince ortaya çıkan değişiklik ve tadilatlar bu üç boyutlu modeller ve görselleştirme sayesinde azaltılır.

Bu tez Yapı Bilgi Modellemesinin proje çizimlerine ve metraja olan yararları ile ilgilidir. Bu tezde bir BIM programı olan Autodesk Revit Architecture ve geleneksel yöntem olan AutoCAD kullanılmıştır. Bu tezde bir apartman projesi seçilerek hem AutoCAD hem de Autodesk Revit Architecture kullanılarak proje çizimleri hazırlanmıştır ve her iki programın proje çizimleri üretmedeki hızları karşılaştırılmıştır.

Ayrıca, Autodesk Revit Architecture ve Autodesk Quantity Takeoff programı kullanılarak elle yapılan metraj hesaplamalarına göre daha doğru ve daha hızlı metraj elde etme olasılığı karşılaştırılmıştır.

Ayrıca bu tezde iki anket yapıldı. Anketlerden birtanesi AutoCAD ve Autodesk Revit Architecture programlarının avantajları ve dezavantajları ile ilgili görüşmeydi ve proje çizimlerini hazırlayan dört mimar arasında yapıldı. Diğer anket ise proje süresinin uzamasına etki eden ve tadilat ve tasarımda oluşan değişikliklere etki eden faktörlerin etkilerini ölçmek için KKTC'deki yirmi inşaat şirketi arasında yapıldı.

Bu tezden çıkarılacak sonuç doğrultusunda, daha hızlı proje çizimleri hazırlamak ve daha kesin ve hızlı metrajlar elde etmek için KKTC' de BIM kullanılmalıdır. Ayrıca KKTC'de inşaat sektörünü geliştirmek için BIM kullanılmalıdır çünkü anketler doğrultusunda müşterinin sürekli değişen talepleri proje süresinin uzamasında ve tasarımda yapılan değişiklik ve tadilatların oluşmasına etki eden en önemli faktör olarak görüldü ve eğer BIM kullanılırsa, üç boyutlu görselleştirmelerle ve projenin daha iyi anlaşılması ile bu sorunun boyutu azaltılacaktır ve projeler zamanında ekstra maliyetlere sebep olmadan tamamlanacaktır ve yapım esnasında ortaya çıkan yıkım ve tadilatlar azaltılacaktır.

Anahtar Kelimeler: Yapı Bilgi Modellemesi, metraj çıkarma, tadilat ve değişiklikler, zamanında tamamlama

ACKNOWLEDGEMENT

I would like to thank Prof. Dr. Tahir Çelik for his continuous support and guidance in the preparation of this study. Without his invalueable supervision, all my efforts could have been short-sighted.

Also, I would like to thank my family and my dear friends for their continuous support throughout my studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

1.1 Introduction

Every project is unique in the construction industry and each project is expected to be completed on time within the budget and defined scope. The overall planning, control and coordination of the project from the beginning to the end aims to meet the demands of clients and ensure the completion is reached on time within required quality standards and budget.

In North Cyprus, traditional methods are used by construction companies in terms of producing project drawings, calculating bill of quantities and managing projects. Generally, 2D paper based drawings are produced with AutoCAD and bill of quantities are calculated manually. However, according to the size of the construction projects, it may be much more complex and more difficult to manage with traditional methods (Alshawi and Ingirige, 2003; Chan et al., 2004; Williams, 2002) because this paper based systems are limited, slow, inefficient, they do not have integration and they can cause poor coordination.

Construction projects have five stages that are briefing, designing, tendering, constructing and commissioning. At the briefing stage, client defines all the needs and demands, and the design team produces drawings according to the demands of the clients at the design stage. However, with the two dimensional drawings, client may not understand the design and since client does not get realistic appreciation from 2D project drawings, reworks arise when construction starts. Also, when AutoCAD, traditional way of producing project drawings is used, if any change occurs in plan, changes should be drawn again in sections and in other views that may lead errors in drawings and causes waste of time.

In addition to that, the bill of quantities of the construction projects is generally calculated manually for estimation purposes and obtaining of accurate bill of quantities is a very important part of estimation because scheduling, planning and cost estimation are generated over the quantities. Manual calculation of bill of quantities is a very time consuming process, it can cause mathematical errors and different cost alternatives may not be considered due to insufficient time. Therefore, if estimation is prepared well, the accuracy of estimation will be high depending on whether there is adequate time to collect more information about the costs or not. On the other hand, estimation department in the construction company plays a big role to win more jobs by bidding.

Planning of each activity also plays an important role in the duration of projects so that if project planning softwares are not used, duration of activities in construction projects that includes beginning and end date can not be determined. However, with the traditional methods, project time can extend because there are some factors that affect project duration negatively. Occurring of design errors, reworks and changing client demands can affect project duration and lack of understanding of the project by the clients. 2D drawings can lead to variation orders and consequently cause extension in the duration of project and may increase the project cost.

Therefore, there is high possibility of having too many problems in construction projects depending on the size and complexity of construction projects. Extension of construction duration, increase in project cost and arising reworks during construction are the most important problems that may arise in construction industry. Quality, cost and time are important factors in projects so these factors can be achieved by using Building Information Modeling (BIM) to minimize reworks and extension of construction duration, by obtaining fast and more understandable project drawings that include three dimensional models and by obtaining fast and more accurate bill of quantities.

Building Information Modeling (BIM) is a new technology in the built environment that uses a multi-dimensional model which includes intelligent objects unlike CAD. It enables to obtain more accurate quantity takeoffs, 3D design functions, project scheduling, 4D sequencing, material sequence, site planning and cost estimation functions. It has the ability to behave as a communication and information resource during the life cycle of construction project (Bazjanac, 2006). Designer and builders can use BIM models for marketing and visualization purposes because realistic renderings allow stakeholders to visualize facilities. 3D walkthroughs can also be provided (Whyte 2002; Whyte et al. 2000). 3D BIM models can be used for cost estimating purposes and it is possible to establish direct link between 3D model and estimating software (Staub-French et al. 2003a,b). In addition, project managers can use 4D BIM models which is the integration of 3D model and schedule to analyze construction operations and activities which are completed and which are under construction at a particular time (Williams 1996; Song and Chua 2006; Hartmann and Fischer 2007). Moreover, better design and construction documents can be developed by using of 3D and 4D BIM models (Gao et al. 2006; Sacks et al. 2004).

Therefore, BIM can be used at all stages of construction projects to improve construction process and project parties can use BIM models to produce more accurate and fast project drawings, cost estimation and etc.

In this thesis, four storey apartment building that has 985 m^2 area was selected to prepare the drawings by using AutoCAD and Autodesk Revit Architecture. It was a reinforced concrete structure and its ground floor has an area of 255 m^2, the first and second floor has an area of 255 m^2 each and third floor has an area of 220 m^2. The ground floor, first floor and second floor are comprised of two similar flats.

There are different type of BIM softwares such as Autodesk Revit, ArchiCAD, Bentley and Naviswork. In this thesis, Autodesk Revit Architecture was used as BIM software and four architects who know to use both AutoCAD and Autodesk Revit Architecture were found to prepare the drawings of apartment building by using both softwares. Autodesk Revit Architecture is the most commonly used BIM software and it has many advantages. For example, it provides fast and accurate project drawing generation, fast and accurate quantity takeoff extraction, visualization and etc. Therefore, project drawings were produced by these four architects using both AutoCAD and Autodesk Revit Architecture. The time and and efficiency in preparing the drawings of both softwares were compared.

Moreover, Autodesk Revit Architecture was used and model which was produced in Autodesk Revit Architecture was exported to Autodesk Quantity takeoff to extract the architectural bill of quantities. Also, the architectural bill of quantities of that building was calculated manually to compare the time for calculations and the accuracy of the results with automatically obtained bill of quantities.

Also, a questionnaire was conducted among construction companies in North Cyprus to investigate the major factors for reworks and extension of project duration in constructions.

It was obtained that, AutoCAD, a traditional way to generate drawings, consumes more time than Autodesk Revit Architecture. Unlike Autodesk Revit Architecture, side views, sections and plans must be drawn separately in AutoCAD. Autodesk Revit Architecture is more practical than AutoCAD and project drawings can be obtain faster. Plans, side views, 3D model and sections can be generated automatically in Autodesk Revit Architecture.

In addition to that, fast extraction of quantities from Autodesk Quantity Takeoff and Autodesk Revit Architecture and more accurate results have positive effects on estimation process that can increase the competitiveness in market and help to the contractor to win more bids.

Also, by conducting a questionnaire among construction companies in North Cyprus, the most important factors that affect both rework and construction duration was found as the clients' continuous changing demands. Therefore, using of BIM technology can help to minimize some of the problems that may arise during construction phase too because client can get realistic appreciation from projects at the beginning and possible changes can be done during designing stage. The reworks and extension of duration can be minimized too.

1.2 Scope and Objectives of Research

The scope of this research includes comparing the efficiency of both AutoCAD and Autodesk Revit Architecture in terms of duration of producing project drawings.

Also, this research includes the comparison of the accuracy and calculation duration of the architectural bill of quantities that were calculated by selected experienced four civil engineers manually with the one way extracted automatically from Autodesk Quantity Takeoff and Autodesk Revit Architecture.

In addition, the aim of this thesis is to find out the most important factors that affect reworks and the extension of duration of the construction projects. Therefore, the major objectives of the research are as follows:

1. To compare the efficiency of the Autodesk Revit Architecture and AutoCAD in terms of duration of producing project drawings at the briefing and design stages of construction projects.

2. To compare the possibility of preparing more accurate bill of quantities and the duration of preparing by using Autodesk Quantity Takeoff, Autodesk Revit Architecture and manual calculations. Meanwhile to compare the time that was spent in both manual calculations and by using software.

3. To find out the most important factors that affect the extension of the project construction duration and the reworks.

4. To investigate the contribution of Building Information Modeling to construction industry.

1.3 Framework of Study

1. Books, articles and websites regarding Building Information Modeling were studied and Autodesk Revit Architecture which is one of the mostly used BIM software was learned. In addition, four storey apartment building project

was selected to prepare project drawings by using both AutoCAD and Autodesk Revit Architecture. Also, a survey was carried out with four architects who produced project drawings in both AutoCAD and Autodesk Revit Architecture to determine efficiency and time spent in both softwares.

2. The architectural bill of quantities was calculated manually by the selected experienced four civil engineers. Then architectural bill of quantities was extracted in Autodesk Revit Architecture and the model that was produced in Autodesk Revit Architecture was exported to Autodesk Quantity Takeoff to obtain architectural bill of quantities automatically. The durations and accuracy of obtaining the architectural bill of quantities for the exactly the same building in each process was compared.

3. Another survey, a questionnaire, on the factors affecting reworks and the extension of the project construction durations was conducted among construction companies in North Cyprus.

1.4 Achievements

1. Autodesk Revit Architecture is faster and practical software than AutoCAD and project drawings can be produced in less time by using Autodesk Revit Architecture. Also, when the floor plan is produced in Autodesk Revit Architecture, 3D models, views and sections can be obtained automatically and if any change is done in the floor plans, it is changed automatically in all other views and sections.

2. Autodesk Quantity Takeoff and Autodesk Revit Architecture are practical and extract bill of quantities automatically and faster. Manual calculation of bill of quantities took much time and the calculated bill of quantities by four civil engineers had small accuracy problems. Therefore, Autodesk Quantity Takeoff and Autodesk Revit Architecture provide automatic, fast and accurate quantity takeoff.

3. From the questionnaire that was conducted among construction companies, it can be concluded that the most important factor of both reworks and extension of duration was the changing demands of clients during the construction stage.

1.5 Overview of the Thesis

Chapter 1 is mainly taking into account the objectives and significance of this study, framework of study and achievements of the research.

Chapter 2 covers an extensive overview of literature about the Building Information Modeling, advantages and disadvantages of BIM, AutoCAD, BIM softwares, quantity takeoff, visualization, client satisfaction, collision detection, reworks, construction documentation, collaboration and cost estimation.

Chapter 3 includes the methodology that has been applied in this research, project description about four storey apartment building, drawing procedure of apartment building by four architects in both AutoCAD and Autodesk Revit Architecture, manual bill of quantity calculation procedure that were calculated by four civil engineers, procedure of extraction of bill of quantities from Autodesk Revit

Architecture and Autodesk Quantity Takeoff and comparison of conventional methods and 4D BIM models.

Chapter 4 includes questionnaire that was conducted among four architects who produced project drawings in both AutoCAD and Autodesk Revit Architecture and it includes what type of questions were asked to architects. Also, this chapter includes questionnaire that was conducted among construction companies in North Cyprus and how questionnaire was formed and what type of questions were included in it.

Chapter 5 is on the results of the study, findings from questionnaires and discussion of results. It includes results of questionnaire among architects, manual bill of quantity calculation results, bill of quantities that were extracted from Autodesk Quantity Takeoff and Autodesk Revit Architecture and results of questionnaire among construction companies in North Cyprus.

Chapter 6 includes conclusion of the study.

Chapter 2

BUILDING INFORMATION MODELING (BIM)

2.1 Introduction

In this chapter, firstly brief history about Building Information Modeling (BIM) is given. Then general information about BIM is provided and its advantages and disadvantages are discussed. After that, AutoCAD which is known as traditional software to produce project drawings is discussed. Then, some BIM softwares are explained by in terms of usage, features, advantages and disadvantages by the help of literature.

BIM application areas are discussed by giving detail information about visualization, quantity takeoff, client satisfaction, collision detection, reworks, construction documents, collaboration and the cost estimation is explained.

Lastly, a brief information about BIM implementation in construction projects is provided.

2.2 BIM History

Before 1980's, architects traditionally expressed building components in symbolic language and orthographic drawings that means drawings were produced manually with pencils and T-squares. Then, geometry-based CAD (Computer Aided Design) such as AutoCAD was used in the early 1980's to automate these procedures up to the introduction of object-oriented CAD such as Architectural Desktop in the early 1990's. Recently, BIM (Building Information Modeling) is a new way that is used to manage complex construction projects by providing good opportunities for architecture, engineering and construction (AEC) industry (Bedrick, 2005).

2.3 BIM Model

BIM improves building design practices and it makes the construction process easier and faster for everyone involved.

Building object is described with graphical information such as lines and vectors in older CAD applications. However, besides graphical information, more information can be added to 3D model with complex surfacing and advanced definition tools (Eastman, *et al.*, 2011).

BIM includes graphical and non-graphical data and it is made up with intelligent objects. The object model defines all entities, relationships and attributes. The model data can be stored in databases and by using of relational databases, graphical and non-graphical information in building component can be accessed, extracted and retrieved such as plans, cost and schedules (Hunt, 2005; Wijayakumar& Jayasena, 2013; Woo, 2007). For example, information in building model can be extracted to generate construction drawings, quantity takeoff and specifications. Therefore, it can decrease time that is needed to generate construction drawings, quantity take off and so on because when 3D model is created, plans, sections and elevations can be obtained automatically with just a few mouse clicks.

In addition, object-based parametric models include families such as windows, doors, walls and components and these models can be modified. For example, a door in model is not just shown by lines, it includes information about manufacturing, locating, installing, finishing and maintaining. Also, a door knows that it is a door and it can only be attached to wall.

Also, 3D parametric object which is a key component of BIM technology has parameters that determine object's geometry, features and properties and due to the link between parameters, when any change is done in objects, all related views, plans, sections, schedules and bill of materials are automatically updated and all views are represented in a coordinated way (Eastman, 2008).

2.4 Building Information Modeling (BIM)

Construction projects are expected to be completed within budget, on time and within required quality standards that aims to meet the demands of clients. However, construction projects are getting more complex and when fast project delivery is needed, it may be difficult to achieve the aims and finish the project on time, in the budget with traditional 2D drawings (Douglas, 2010). However, BIM (Building Information Modeling) which is a latest technology in construction industry is the process of designing, integrating and documenting of construction projects by using intelligent virtual prototype instead of using 2D CAD and puts them on a virtual environment and provides better efficiency, collaboration and communication (Douglas, 2010 ; Lee, 2008).

BIM is also defined as "nD" modeling that provides to add number of dimensions to the building model (Aouad, 2006) as it can be seen in figure 1. It does not just include creating of 3D model, it is the process of creating intelligent 3D data set and sharing quick and reliable data among project stakeholders to improve collaboration between project team because it acts as a communication and information resource over the lifecycle of a construction project (Gee, 2010). As well as 3D dimensional design functions, 4D BIM models that have programming and scheduling functions, 5D BIM models that have cost estimating functions and 6D facility management functions can be generated too. The model is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which the views and data appropriated to various user needs can be extracted and analyzed to generate information that can be used to make decisions and to improve the process of delivering the facility and a computer generated model is used to simulate the planning, design, construction and operation of a facility (AGC, 2005).

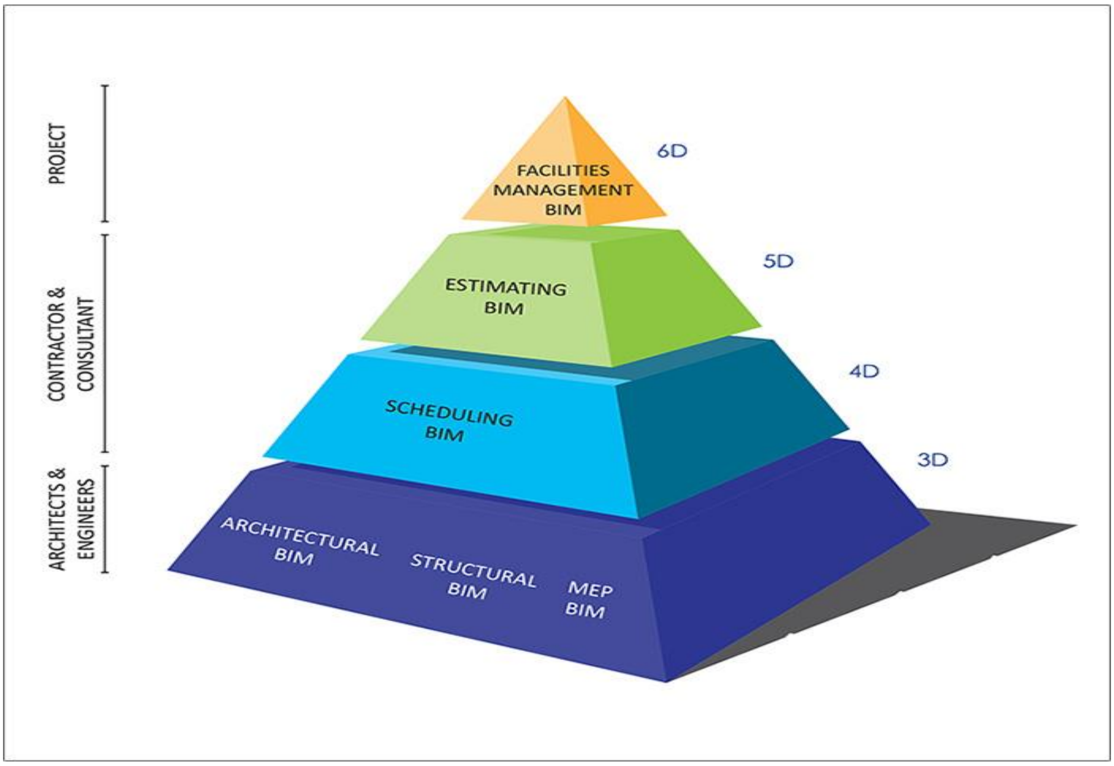

Figure 1. BIM application areas (http://www.aristeo.com/?page_id=1739)

BIM enables more engineering analysis and various construction business functions. For example, engineering analyses for structure and energy can be provided, disaster prevention in the design stage can be provided. Also, it provides construction planning, scheduling, controlling and safety in the construction stage, and interactive systems can be provided in the maintenance stage (Wang, Truijens, Hou, Wang & Zhou, 2014).

BIM technology has positive effects on construction projects because it produces a specific outcome such as model generation, drawing production, specification writing, cost estimation, clash and error detection, energy analysis, rendering, scheduling, and visualization (Eastman, *et al.*, 2011) and conflicts can be determined and resolved at design stages of construction projects and solutions can be developed before construction starts on field.

Therefore, it can be used at all stages of the project life-cycle because it is “a systems approach to the design, construction, ownership, management, operation, maintenance, use, and demolition or reuse of buildings” (Smith, 2009). For example, owner can use it to understand project, design team can use it to design and develop faster and accurate project drawings at design stage which are more understandable than 2D CAD drawings because BIM softwares provide obtaining elevations, plans, sections and views from model automatically. Also, contractor can use it to manage projects at construction stage and it can be used by facility manager during operation therefore it can improve construction stages and client can be happy with the end product (Grilo and Jardim-Goncalves, 2010). As it can be seen in figure 2, BIM is virtual process that includes all aspects, disciplines and systems of facility within a single virtual model and it allows all project members such as owners, architects, engineers, contractors, subcontractors and suppliers to have more accurate and efficient collaboration than traditional methods (Carmona and Irwin, 2007).

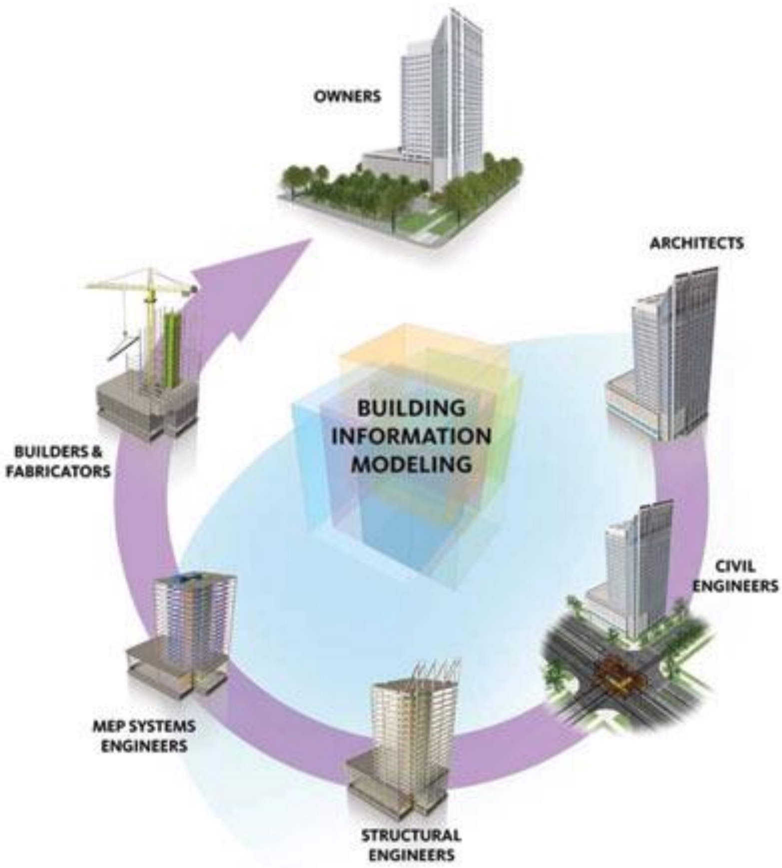

Figure 2. Relation between project stakeholders during lifecycle of building

BIM models can be created also for visualization. 3D models help clients to understand project better and they can get realistic appreciation from the projects with visualization feature of BIM. On the other hand, possible design changes can be done at the designing stage of construction projects and since clients can understand project better with 3D models, necessary changes can be done before construction starts at field so that reworks, possible design changes and extension of project duration can be minimized. Also, client satisfaction can be increased because 2D CAD projects may not be adequate to satisfy client demands.

In addition, planning and construction scheduling can be generated by integrating 3D model with time which is called 4D BIM model. This 4D BIM model can help to improve estimation process of construction projects because planning and scheduling are the important parts of estimation and it helps to minimize time that is needed to determine planning and scheduling.

Moreover, 5D BIM model which is the integration of 4D model with cost can be generated and more accurate cost estimations can be obtained with BIM technology.

At tendering stage of construction projects, BIM helps to obtain fast and more accurate bill of quantities due to automatic quantity takeoff feature of BIM softwares instead of looking at 2D drawings and measuring each dimension and calculating bill of quantities manually. Also, planning, scheduling and cost estimations can be generated with BIM technology.

In addition, possibility of arising of reworks and design changes can be minimized because possible changes, collisions and changing demands of clients that cause reworks when construction starts at field can be fixed at designing stage and extra cost and extension of construction duration due to these reasons can be minimized too.

Since real life conditions are modeled with BIM, the end product is known before starting the project on site. Therefore, reworks in the field can be reduced, client satisfaction is increased due to visualization and better interpretation of the project, extra cost that may occur due to reworks and client changing demands can be decreased. Therefore, BIM can help to improve accuracy, efficiency, and productivity of construction projects due to intelligent models so that it allows on time completion and cost savings. Also, more predictable outcomes and faster project approvals are obtained and it helps to improve collaboration and better sharing of information between project parties (Holness, 2008).

Another feature of BIM technology is that digital data can be extracted, modified, updated and inserted easily by project parties. So, since project parties work on the same model, collaboration between different stakeholders can be improved as well (Saleh and Smith, 2006). Also, when the design changes, the data remains consistent, coordinated, and more accurate across all stakeholders.

2.4.1 Advantages of BIM

As it is mentioned above, BIM has lots of benefits. When construction projects are managed with traditional methods and paper-based tools, it may be difficult to finish projects on time and under budget. With BIM technology, architects can produce 3D, 4D and 5D model that show every little detail in model and by minimizing the reviews and reworks, time can be saved and projects can be completed under budget by saving time and money (Post, 2006) and productivity in construction projects can be increased, collaborative design and coordination can be achieved, accurate and faster design decisions can be done at early stages, accurate and faster quantity takeoff can be obtained automatically, reworks and material wastes can be minimized because with the ability of BIM technology design conflicts can be determined before construction starts on site (Condit, 2006) and errors can be minimized that can reduce delays and reworks resulting in cost overruns (Smith, 2009; Kymmell, 2008; Hardin, 2009; et al). Also, prefabrication that reduces accidents, increases efficiency, and reduces labor time in the field is another advantage of BIM.

Therefore, AEC professionals can use BIM to support distributed work processes with multiple team members since all parties work on the same project, to generate realistic renderings and animations, to integrate 3D BIM models with cost estimating, energy analysis, project management, and structural analysis applications and to generate quantity takeoff, estimating and 4D scheduling (Bynum, Issa & Olbina, 2013).

2.4.2 Challenges of BIM

BIM is not a golden egg laying goose, there are certain disadvantages it posseses. Since BIM is a newly recognised technology in construction industry not all construction firms are familiar with this new technology.

In order to get BIM, construction firms need to buy and install necessary software and hardware; also, the staff should be trained to learn to use the software. Above all, adoption of bran-new technologies has always been painful and resistance to the change is a challenge on its own (Rajendran and Clarke, 2011). Therefore, people should also be trained about the value of BIM so that they appreciate the change towards that technology.

One of the other disadvantages of using BIM is that during the information exhange, different parties in the project may use different software and tools so that this difference causes difficulty in model exchanging because different software may define information differently (Man, 2007).

Another challenge of using BIM is that clear understanding of the responsibilities of different stakeholders in the new process by construction lawyers and insurers may not exist (Arayici et al., 2009; Eastman et al., 2008).

2.5 AutoCAD

Data in 2D model is represented graphically such as lines, arcs, circles and symbols. For example, walls, windows and doors are represented with lines and all the views, plans and sections must be drawn manually. 2D drawings are not connected to each other and when the building is drawn by 2D views, if any change is done on plans, sections and elevations, all other views must be checked and changed individually. This takes time and increases the likelyhood of making a mistake and leads to poor documentation in the end.

In addition to that, it becomes even more time consuming since the final drawings are needed to be checked again. Also, any change in drawings affects quantities, cost estimations, and production plans directly (CRC Construction Innovation, 2007).

2.6 BIM Softwares

Building Information Modeling has different types of softwares. There are softwares for architecture, structure, sustainability, MEP, construction and facility management purposes. For example, Autodesk Revit Architecture, Graphisoft ArchiCAD**,** Nemetschek Allplan Architecture**,** Gehry Technologies- Digital Project Designer**,** Nemetschek Vectorworks Architect**,** Bentley Architecture**,** 4MSA IDEA Architectural Design (IntelliCAD), CADSoft Envisioneer, Softtech Spirit, RhinoBIM (Beta) are some of softwares that are used for architectural purposes.

In addition, Autodesk Revit Structure, Bentley Structural Modeler, Bentley RAM, STAAD and Prosteel, Tekla Structures, CypeCAD, Nemetschek Scia, Autodesk Robot Structural Analysis and Graytec Advance Design are some of the softwares that are used for structural purposes. Also, there is Autodesk Revit for mechanical, electrical and plumbing (MEP) engineers.

2.6.1 Autodesk Revit Architecture

Autodesk Revit is one of the Building Information Modeling software that is used by architects, structural engineers, engineers, mechanical electrical and plumbing (MEP) engineers, designers and contractors to draw projects.

Autodesk Revit is the most widely used solid modeler on the market (http://usa.autodesk.com/adsk/servlet/pc/index?siteID=123112&id=8479263) because it is easy to use and it can be easily integrated with what other firms are using. Revit has approximately 80% of the market and it is used mostly by architects and contractors (Autodesk, 2008; Douglas, 2010).

Autodesk Revit uses building elements such as walls, windows, doors, beams, columns, floor and roof as building component instead of lines, circles and squares. It also has an extensive library of objects. With this software, 3D models can be created and floor plans, side views, elevations and sections can be obtained directly and if all project members use the same authoring tool, data can be exchanged easily between project members (Douglas, 2010).

The objects in the model have dimensional properties such as lengths, areas, and volumes. Objects are also linked to each other and if any change is made at plan, sections, elevations, views and 3D views are automatically updated. Also, when new building components are added to model, it automatically changes all project drawings because it has ability to coordinate every building element in one database so any revisions made in the model, that change can be reflected in the other views (Howeell and Batcheler; Sah and Cory, 2009).

Project drawings can be produced which include 2D drawings, 3D drawings, elevations, section, rendered drawings for client feedback, 3D perspective views, and animated walkthroughs. In addition, it is very easy and practical to cut section by adding a section cutting line that produces automatic section drawings. However, everything should be drawn manually and separately in AutoCAD that causes waste of time (Woo, 2007).

Autodesk Revit has the bill of material functions in their BIM applications to enable construction estimation and procurement (Shen and Issa, 2010). Therefore, estimators can extract amount of quantities from these 3D models automatically (Autodesk Inc., 2005a).

In addition, the project can be easier to be interpreted due to allowing people to visualize easily since the virtual tour of the building can be performed, different light effects can be produced and realistic rendering drawings can be obtained.

Elements in Autodesk Revit are classified by categories, types, families and instances. A category is a group of elements that is used to model or document a building design such as walls, columns, and beams. Families are classes of elements in a category and a family gathers the elements with a common set of parameters having similar graphical representation and identical use; for example families include round, square and circular columns (Meadati and Irizarry).

Time can be saved and errors can be reduced with Autodesk Revit and this in turn enables construction companies to increase quality and level of service to clients.

2.6.2 Bentley Architecture

Bentley includes products for architecture, engineering and construction. Bentley Architecture is easy to use designing tool and it can be integrated with softwares that can be used in all stages of building lifecycle such as Bentley Structural Modeler, Bentley Building Mechanical Systems, Bentley Building Electrical Systems, Bentley Facilities, Bentley Generative Components and Project Wise Navigator (Jiang, 2011)

Bentley products are in version V8i and “i" shows five key new capabilities and enhancements: more intuitive conceptual modeling capabilities; interactive dynamic views; intrinsic geo-coordination capability; incredible project performance and speed; and finally, a high degree of interoperability. Bentley Architecture V8i integrates design and visualization. Quantities, cost calculations and schedules can be obtained and they can be linked to Microsoft Excel spreadsheet templates for further formatting and processing.

Also, rapid design changes can be made due to relationship between architectural elements. Plans, elevations and sections can be generated easily.

Bentley Architecture provides to compare different design options and to predict cost. Visualization, quality, collaboration and coordination between project stakeholders can be improved and time can be saved due to interactive dynamic views. 2D documentations and 3D models can be created and produced in less time.

It also provides rendering and it supports DGN, DWG, DXF, PDF, STEP, IGES, IFC, and other major industry standards. It prevents delays in projects and cost overruns, improves client satisfaction and helps to increase revenue.

2.6.3 ArchiCAD by Graphisoft

Graphisoft is one of the earliest companies to market BIM capabilities and ArchiCAD which is an only object model oriented architectural CAD system that runs on the Apple Macintosh (Eastman *et al.* 2008). Today, ArchiCAD can both serve Windows and Apple Platform.

The Graphisoft enables to create 3D structures with “smart objects” such as walls, doors, windows, slabs, roofs and furniture. Also, plan and elevation views can be obtained from 3D models.

When 3D model is created, structurally correct sections can be provided. Also, when 3D model is created, all documentation and images can be created automatically. With the teamwork technology, team can work on different aspects of same project. From 3D model, sections, elevations, plans, bill of quantities, renderings and schedules can be extracted.

It has also ability to cut sections with planes that enhance visualization. It has energy analysis ability and a real time 3D navigation that has fly mode, presaved walkthroughs and layer control. In addition, it has connection with Google Earth and Sketch Up and models can be opened with Google Earth and Sketch Up.

It has also object library for users and in addition to that, energy analysis function can be conducted due to its built-in analysis tool. However, it doesn't have automatic update to related objects.

It has Maxon for curved surface modeling and animation, ArchiFM™ for facility management Sketchup™ for 3D sketching and MEP modeler for modeling pipes.

2.6.4 Vico Construction

Vico Constructor is modeling software by Vico Software, Inc., that can work effectively with scheduling and estimating modeling tools.

Vico Software Inc. includes BIM software packages that are Constructor, Estimator, Control and 5D presenters. Constructor is used to generate Building Information Model and Estimator is used to estimate quantities and costs by importing 3D model from Constructor to Estimator. Vico's Estimator software features include processing of quantities, tracking of model revisions, addition of margins, and creation of bid packages.

2.6.5 Nemetschek

The AllPlan database is "wrapped" by the Nemetschek Object Interface (NOI) layer to allow design and analysis applications to interface with the building objects in the model. This layer supports also IFC objects.

2.7 BIM Application Areas

2.7.1 Design

Building is designed with intelligent objects and architects, structural engineers and MEP engineers can work on the same building model due to the object-based parametric modeling feature of BIM. Due to the practicability of BIM softwares, design process can be facilitated and more accurate construction drawings and high quality 3D renderings of building can be generated (Jiang, 2011).

If BIM is compared with traditional methods, there is no risk of forgetting to update changes in design because any change in any view is automatically updated in all relevant plans, views, sections and elevations. For example, lines are used to draw wall in CAD and if width, height or length of wall is needed to be changed, it should be changed manually and all other related parameters should be changed one by one that increases the risk of forgetting to update changes. However, BIM facilitates design change process because if any design changes occur in objects, it is automatically updated in other related objects therefore it reduces errors and omissions that may occur in CAD design. Also, 3D view, side views, plans and sections can be generated automatically from the design model.

According to the 2010 SmartMarket Report on BIM in Europe, in Western Europe, 70% of architects believe that using BIM provides better-designed projects and avoids delays in the field.

2.7.2 Collaboration

Collaboration between architects, structural engineers, mechanical engineers, electrical engineers and contractors is very important to improve construction processes. CAD systems are used in construction industry but there is difficulty to share and exchange information in construction among different design phases and aspects (Emmerson, 1962; Latham, 1994; Egan, 1998).

BIM provides better communication and easier change and sharing of information and it allows more effective and faster processes by letting people to work together in real time because it enables engineers, architects, owners, contractors and facility managers to share and exchange information (Eastman, 1999) and communication and collaboration among all project stakeholders can be improved.

It is also collaborative tool that reduces construction conflicts due to visualization of product because models can be coordinated with others before construction starts on field and conflicts can be resolved that reduces also rework and change orders (Eastman et al., 2011).

2.7.3 Quantity Takeoff

Quantity takeoff is the most important part of cost estimation and quantity surveyors are responsible from bill of quantity calculations. Length, height, number of pieces, perimeter, area, volume and weight are the most common measurements in bill of quantity calculations (buildingSmart, 2013). Bill of quantities is calculated by measuring necessary dimensions and calculating perimeter, area and volume manually.

Quantity takeoff process plays an important role in scheduling, planning, cost estimation and tendering processes. Thus, accurate quantity takeoff results are expected to be obtained to make a good estimation that enables to win the bids because it is one of the most critical tasks concerned by all participants in the Architecture, Engineering, Construction and Facility Management (AEC/FM) industry throughout the lifecycle of a building project (Zhiliang, *et al.,* 2010). Quantity surveyors are responsible of the management of the costs of the whole project from beginning to the end (Gee, 2010).

When traditional methods and 2D drawings are used to calculate bill of quantities, areas, volumes, etc. (everything related with quantity) should be measured and each element should be counted manually after drawings are completed but this manual quantity takeoff process may lead to waste of time and errors in calculations and affects estimation process substantially.

In order to obtain bill of quantities, first of all, items and their interrelationships on drawings and specifications are identified and this procedure is followed by measuring and finding dimensions of items from drawings and finally quantities such as length, areas and volumes are calculated. Therefore, it is time consuming process and can cause errors in calculations because errors may be occurred while moving data between files and there is risk of missing elements or double counting of elements (Baldwin and Jellings, 2009). Apart from time and error at the initial stages, it takes more time to revise bill of quantities if any change is done in the design later in the process.

As it is mentioned above paragraphs, 3D models are easy to use, practical and more understandable than 2D drawings due to three-dimensional rich models and visualization feature. With the help of BIM technology, BIM quantity takeoff tools can be used and quantity takeoff process can be automated by extracting quantities to a cost database and more accurate cost estimates can be obtained. Also, accuracy of bill of quantities that can be extracted from BIM model automatically is higher than that of 2D model because it minimizes the possibility of mathematical error. Bill of quantities can be extracted faster and more efficiently from an intelligent model than traditional methods instead of calculating each quantity manually and this automatic and easier quantity takeoff is one of the most important features of BIM (Firat, et al., 2010).

Beside this, BIM helps to reduce duration of bill of quantity calculations with automatic quantity takeoff feature. All of the quantity takeoff software has capability to extract material quantities such as areas and volumes from BIM model (Eastman, *et al*., 2011).

When BIM is used for quantity takeoff, the user assembles the objects in the model and dimensional data will be transferred from the model to quantity takeoff (QTO) list for further pricing. Items that are taken off are visualized and it can reduce the chance of missing items. Also, chance for transposition errors can be reduced because when design changes, estimated quantities are updated (Khemlani, 2006). For example, Autodesk Quantity Takeoff which is one of the BIM tool can automatically extract quantities from model and modifications about takeoff can be done due to preferences. After the automatic takeoff, users can also make some changes on the QTO list manually (Jiang, 2011)

Using of BIM for quantity takeoff purposes, improves the productivity of the estimator because of easier interpretation of the project and faster quantity takeoff so it helps to win more bids thanks to accurate results.

To sum up, time consumed and expenses can be reduced. With the BIM technology, workload of surveyor is reduced during bill of quantity calculations and the time of quantity take off process can be reduced up to 80% (Viklund, 2010). Also, different cost alternatives can be considered by using BIM since construction cost can change dramatically depending on the project design. Therefore, cost of a project is estimated in more detail since quantities are obtained automatically and estimators have more time to consider different cost alternatives (Autodesk, 2007).

In addition, delays can be limited if BIM is implemented in cost estimation because BIM produces rapid cost feedback throughout the lifecycle of building (Tiwari, Odelsan, Watt and Khanzode, 2009).

On the other hand, there are concerns about job availability due to the fact that automatic quantity takeoff capability of BIM can lead to a decrease in the number of quantity surveyors needed in the firms that can decrease salary amounts.

However, when the digital model is designed, cooperation and using of compatible BIM tools between the architect and engineer is required for quantity take off (buildingSmart, 2013).

2.7.4 Visualization

Visualization can be a good way to understand construction projects better by client and this can be achieved easily by using BIM. 2D drawings that are produced by using traditional methods may not be understandable by clients because complex projects can not be imagined with these 2D drawings.

Visualization is based on virtual building and virtual reality technologies are effective tools to improve the understanding of clients about the project and built environment (Shen and Shen, 2011) and to increase the understanding of complex projects and relationships (Card 1999; Kamat 2001; McKinney 1998). Also virtual building that includes smart models can enable improvement in construction projects due to better coordination.

With visualization feature of BIM, 3D visualization programs enable the owners and builders to see what the project may look like in the future. It helps to visualize the project and what is going to be built in simulated environment as an end product so errors and undesired parts in the design can be identified by project parties. Therefore, possible design errors and reworks that may occur in future can be minimized before moving site (Azharet al., 2010).

In addition to that renderings, walkthroughs, and sequencing of the model can be provided by construction manager during the bidding phase of the project to better communicate the BIM concept in 3D (Khemlani, 2011).

Also, 4D products including both 3D model and time can be generated which are called 4D BIM model. So designers and engineers can detect conflicts and possible mistakes that may occur in the future and errors and conflicts can be minimized before the commense of construction. Since time is integrated to 3D model in 4D products, it is helpful for prediction of the schedule and since 3D visualization feature is available, design errors and delays can be minimized as mentioned above (Lee, 2005).

There are two types of virtual models which are surface and solid models. Surface models include information about size, shape and location and these models are only visualization purposes that have been used in 1990s for aesthetic and marketing reasons. Solid models includes more information and they are used for simulation reason (Kymmel, 2008)

2.7.5 Client Satisfaction

Construction projects are designed according to clients' demands and end product should meet with their requirements to satisfy them. However, continuous changing demands of client may make design and construction stages of projects difficult.

Clients may not be a technical people who can read and understand construction projects from 2D drawings therefore they cannot imagine what will be the end product after construction and finished product maynot meet the need of clients (Lertlakkhanakul, Choi, & Kim, 2008).

Therefore, changing demands and lack of understanding of the project by client, because of 2D drawings, have an adverse effect on the progression of the project. There is a limitation for designers to manage and record subsequently changing demands of clients during design and construction stages. Above all, the client may not be satisfied with the end product at all (Kiviniemi, 2005).

With BIM technology, not only the satisfaction of client is increased by showing different design alternatives but also the understanding and interpretation of the project by the client is increased with the visualization capability of BIM technology (Azhar, Hein and Sketo, 2010).

At the end, design is not different from the expectations of client, thus improve the client satisfaction and quality of the final product.

2.7.6 Collision Detection

Collisions that may occur during construction result in rework that increases construction duration and cost. Also, it can cause tension between subcontractors. Therefore, reworks can be prevented and minimized by using BIM since the collisions are detected before starting the construction, at an early stage (Rajendran and Clark, 2011).

With this clash detection ability, coordination among different organizations is enhanced and errors and omissions are significantly reduced that speeds the construction process, reduces costs, and shortens the construction period.

With BIM technology, architects, structural engineers and MEP engineers work on the same model so clashes between activities, conflicts in the plan and inefficiencies in design can be detected before construction starts at site so that clashes can be modified and errors can be corrected before construction starts. Also, extension of project duration and extra cost can be minimized (Ashcraft, 2007).

2.7.7 Reworks

Rework is one of the problems that can arise during construction of projects and it can affect construction duration, cost and quality negatively (Love et al., 1998a).

Changing demands of clients during construction is one of the most important reasons of occurrence of reworks. Other than changing demands, workmanship, errors due to misunderstanding of project, changes in design, experience and education of project staff, change of staff, complexity of project and communication between staff, add up to the possibility reworks. However, the most important factor that increases the possibility of rework is the ‘last minute change from the client’ (Love et al., 1998b). Because clients can not get realistic appreciation from 2D drawings of the project at design stage and when construction starts on site and when they understand project, they try to demand new changes in design.

As a result of misunderstanding of 2D drawings by client, reworks arise and they prolong the duration of construction activities, delay the completion and increase the cost of project. It has been found out that cost of reworks in construction projects is between 2.2% and 12.4% of that of the contract value (Josephson and Hammarland, 1996; Davis and Ledbetter, 1989).

BIM technology uses computer software to produce 3D, 4D and 5D models which are an effective way to solve rework problems. With 3D models, clients can acquire realistic appreciation and they can do decision about design before construction starts on site. So, all these changes are solved during the design stage and due to the visualization ability and walk through ability of BIM, satisfaction of client can increase.

2.7.8 Construction Documents

While using AutoCAD for producing project drawings, plans, views, and sections should be drawn separately and if any design changes occur, these changes should be corrected on each drawing one by one. This process causes waste of time and increases the possibility of error in drawings.

However, when BIM softwares are used to produce project drawings, plans can be produced and views, sections, 3D views, and elevations can be obtained automatically. In addition, when any change is done in any view, it will be automatically changed from all relevant drawings and realistic renderings can also be generated. Therefore, BIM technology enables the company to deliver construction documents with more 3D views, sections, schedules, and realistic renderings. BIM increases efficiency, especially for construction documentation, enabling firms to do more with less.

2.7.9 Construction Planning

The construction planning includes scheduling and sequencing of the model to coordinate virtual construction in time and space and schedule of the construction progress can be integrated to a virtual construction. The utilization of scheduling introduces time as the 4D.

Planning and monitoring is an extremely important part of the construction. The construction manager can use various 4D BIM enabled tools to enhance the quality control process. Overall, construction planning and monitoring with 4D BIM is a great process to build a facility per the designed model.

Building can be linked to project schedule and construction schedule can be synchronized. Also, it allows users to simulate the construction process and show the virtual view of the building (Hergünsel, 2011).

2.7.10 Cost Estimation

Estimation process is one of the most important parts of tendering stage and in order to be able to make estimation, plans and specifications of construction projects are used. Estimator should also take into account the site conditions, probable inflations, potential profits, time and safety considerations before doing estimation.

Quantity takeoff and pricing are the two important parts of cost estimation. Cost estimation is a critical process which is time consuming since interpretation of the project, visualization, specification reading, calculation of quantities of materials, equipment and laborare required (Shen and Issa, 2010) because accurate bill of quantities should be obtained and estimations should be obtained over these quantities.

Depending on organizations, estimation methods can be different. Estimators calculate only the direct cost which includes materials, workmanship and equipment cost. In addition to that, in some cases cost of subcontractor can be added on top of this direct cost calculation. Overhead costs are calculated many times over again and sometimes contractors add overhead and profit on the direct cost. Therefore, tender price includes both direct and indirect costs where risks, profit, cost of materials and cost of labor are included in tender price.

BIM has cost estimating features and bill of quantities can be extracted automatically. At the beginning, cost can be assessed and more detailed cost estimate can be obtained at a more detailed model (Grilo and Goncalves, 2010). Since quantities extracted from BIM model are accurate, BIM would produce a more reliable and accurate cost estimate than traditional methods and when any change occurs in model, faster cost feedback can be obtained on changes in design (Eastman *et al*., 2011). So that productivity of estimator can be improved with BIM.

In addition to that when 4D BIM model is combined with cost, 5D BIM models can be produced and cost estimations can be obtained. Therefore, BIM helps to obtain more accurate and fast quantity takeoff, planning and scheduling can also be obtained with 4D BIM models and 5D BIM model can be used for cost estimations and different cost alternatives can be obtained.

2.8 BIM Implementation

BIM implementation can take years because it is a new approach and people do not have education to use it. Also, initial cost and culture are important problems to implement BIM because initial cost for implementation is expensive but savings can be achieved later. In addition, experienced people in traditional methods do not want to change due to their lack of expertise and familiarity with BIM and culture and staff may insist to use traditional methods in construction projects. Therefore, BIM adoption around the world still is not enough because of several reasons that includes technical issues, such as interoperability, investment, training and organizational issues, such as professional liability and process problems (Won, Lee, Dossick & Wesner, 2014).

Also, in order to be able to use BIM, necessary software and hardware should be bought and there should be training about BIM software functions for designers to learn how to use them efficiently (Douglas, 2010).

Although BIM has existed for over 20 years, it is only in the last few years that construction companies became aware of the benefits and efficiencies of BIM (Coates et al., 2010).

BIM implementation can solve many problems that are faced in construction. Eliminate waste, increase feedback, delay decisions to achieve consensus, deliver fast, build-in integrity, empower the team and see the whole are the seven pillars of BIM implementation strategy (Arayici et al., 2011).

Chapter 3

METHODOLOGY

3.1 Introduction

In this chapter a brief description about preparation of project drawings of 985 m^2 apartment building project by using 2D Drafting (Software: AutoCAD) and Architectural BIM method (Software: Autodesk Revit Architecture) is presented. The procedure of interview that was conducted among architects is explained.

In the architectural bill of quantity calculation part, detailed information about both hand calculations and the BIM was used to extract quantities is briefly explained.

In addition, the comparison between conventional software (Microsoft Project) and 4D BIM are briefly explained.

3.2 Project Description

In this thesis, a reinforced concrete structure of four storey apartment building which has 985 m^2 floor area was selected to prepare the drawings by using both AutoCAD and Autodesk Revit Architecture.

The ground, the first and the second floor has an area of 255 m^2 each and the third floor has an area of 220 m^2. There are two flats on each floor.

3.3 Drawing the Apartment Project

In order to generate drawings of apartment project, architects who are skilled in using both AutoCAD and Autodesk Revit Architecture were needed. Normally, there are kind of BIM softwares that are used to produce intelligent BIM models as it was mentioned earlier in this thesis. However, BIM, a new technology in construction industry is not commonly used in North Cyprus. Since it is not often used in North Cyprus, people are not well aware of BIM and the BIM software trainings are very limited. Therefore, finding architects who know both AutoCAD and Autodesk Revit Architecture was a challenging task. In total the interview is carried out by contribution of 4 different designers. 3 of them are new architecture graduates and they currently work in industry and the final designer is still an architecture student. The 2D drawings of apartment project that included architectural plans, side views and sections were distributed to four architects as hardcopies in A3 file and these A3 hardcopies were used to generate projects drawings in both 2D drafting AutoCAD and the BIM solution of Autodesk Revit Architecture by recording drawing durations of both methods.

Floor plans for all levels, side views and sections were drawn manually by four architects separately according to the originally distributed architectural plans by using AutoCAD. The drawing durations were recorded by architects and they informed the author.

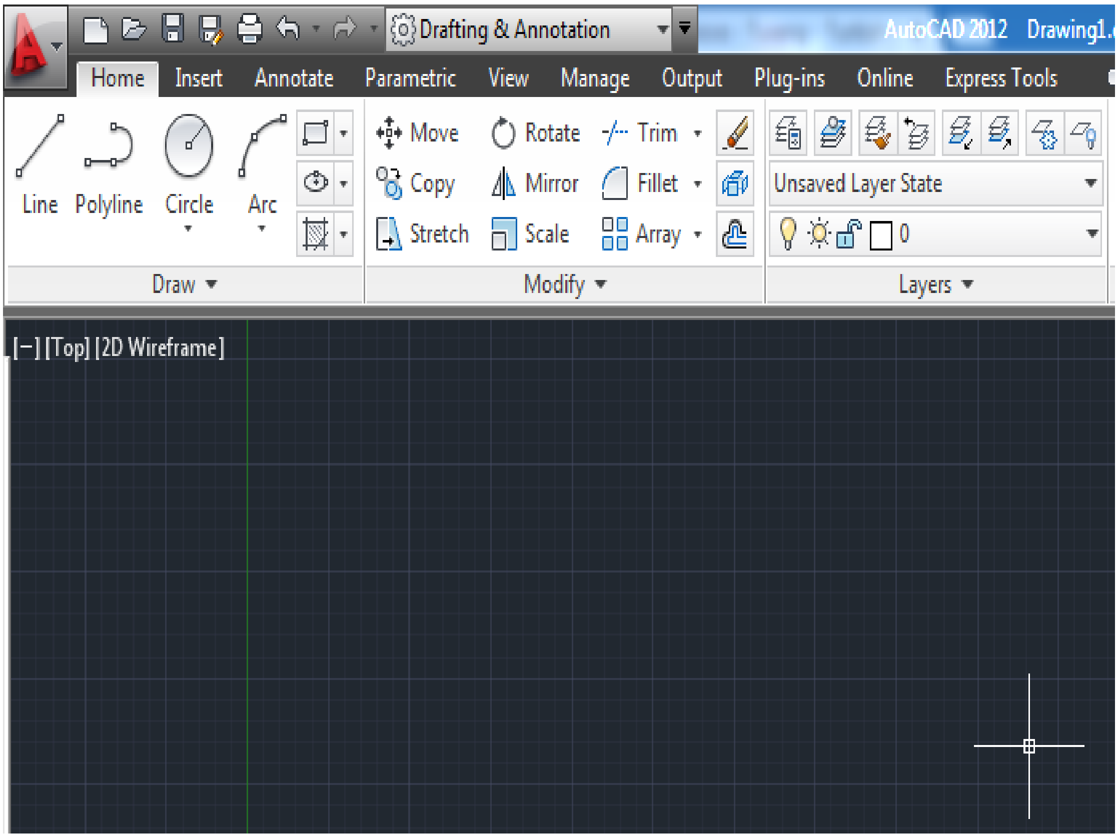

Figure 3. AutoCAD 2012 software

Figure 3 shows the home tab of AutoCAD software. As it can be seen from figure 3, home tab includes line, polyline, circle, arc, rectangle and so on for drawing purposes. Drawings can be modified by modify tool that includes move, copy, rotate, trim, mirror, stretch, erase and so on. Layers also help to define some features for elements such as colour, lineweight and linetype. Therefore, with the help of these tools, projects drawings for apartment project that include plans, sections and views were generated by drawing every detail line by line because elements were represented by lines and elements were drawn for plans, sections and views separately.

Also, the apartment building project drawings were generated by using Autodesk Revit Architecture. Floor plans for all levels, side views, elevations, sections and 3D views were generated. Again as like AutoCAD method, the drawing durations in Autodesk Revit Architecture were recorded and author was informed.

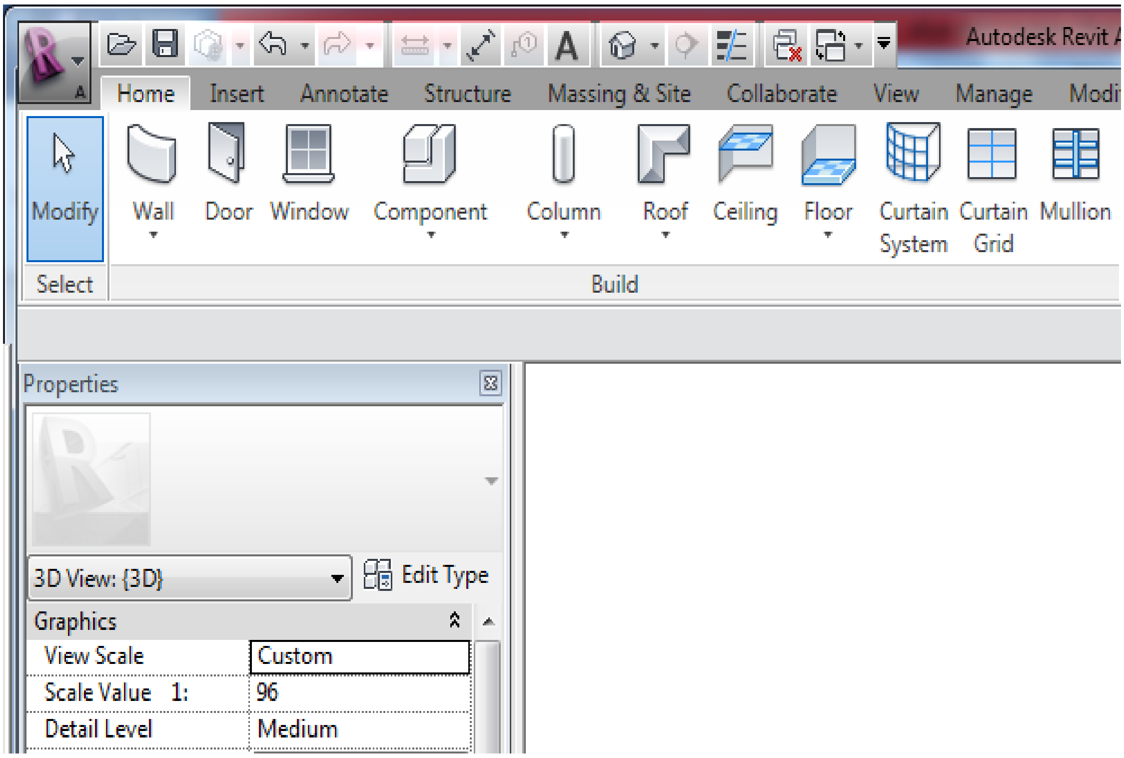

Figure 4. Home tab of Autodesk Revit Architecture 2011

As it can be seen from the figure 4, home tab in Autodesk Revit Architecture includes build option and it includes intelligent objects such as wall, door, window, component, column, roof, ceiling, floor, curtain systems, curtain grid and mullion for drawings purposes. Therefore, building elements were drawn as a single unit. For example, wall can be drawn directly by selecting wall without performing line by line drawings and wall types can be selected from properties menu by editing wall types and selecting the types from library.

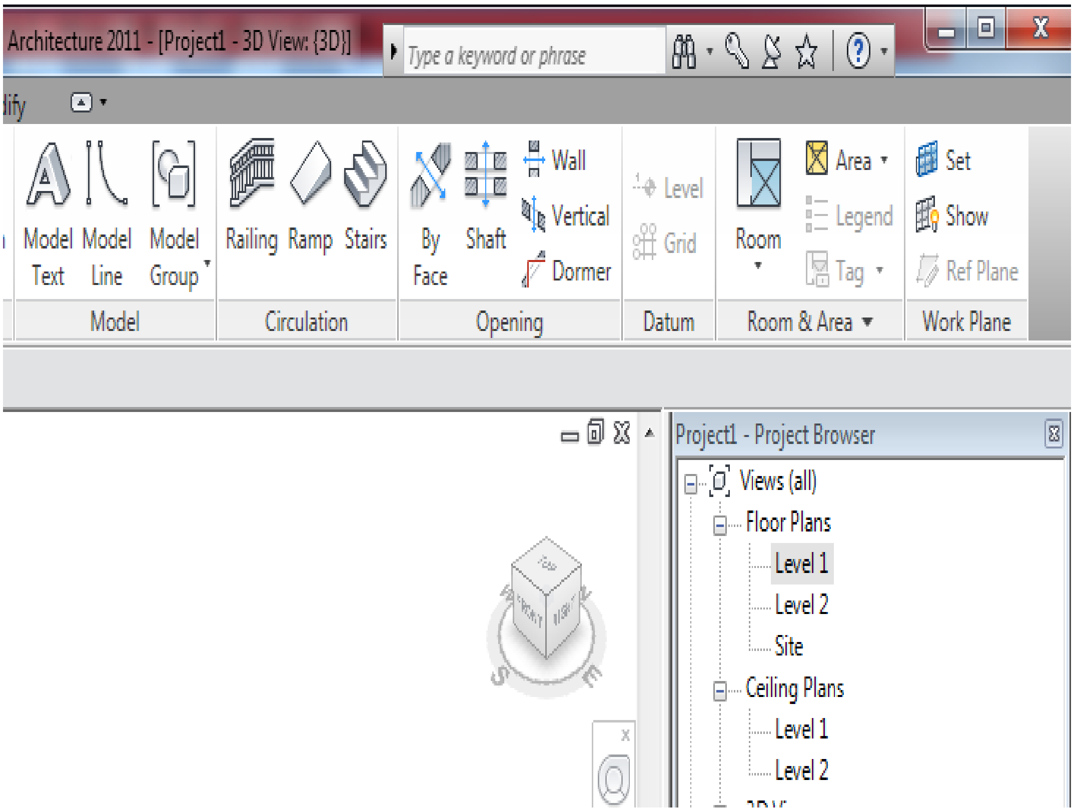

Figure 5. Home tab of Autodesk Revit Architecture 2011

Model, circulation, opening, datum, room and area, and workplane are other tools at home tab as in figure 5. For example, railings and stairs can be directly selected from circulation and their types can be selected from library and they can be located to the plan automatically. In addition, levels and grids can be defined and drawn by selecting them from datum option.

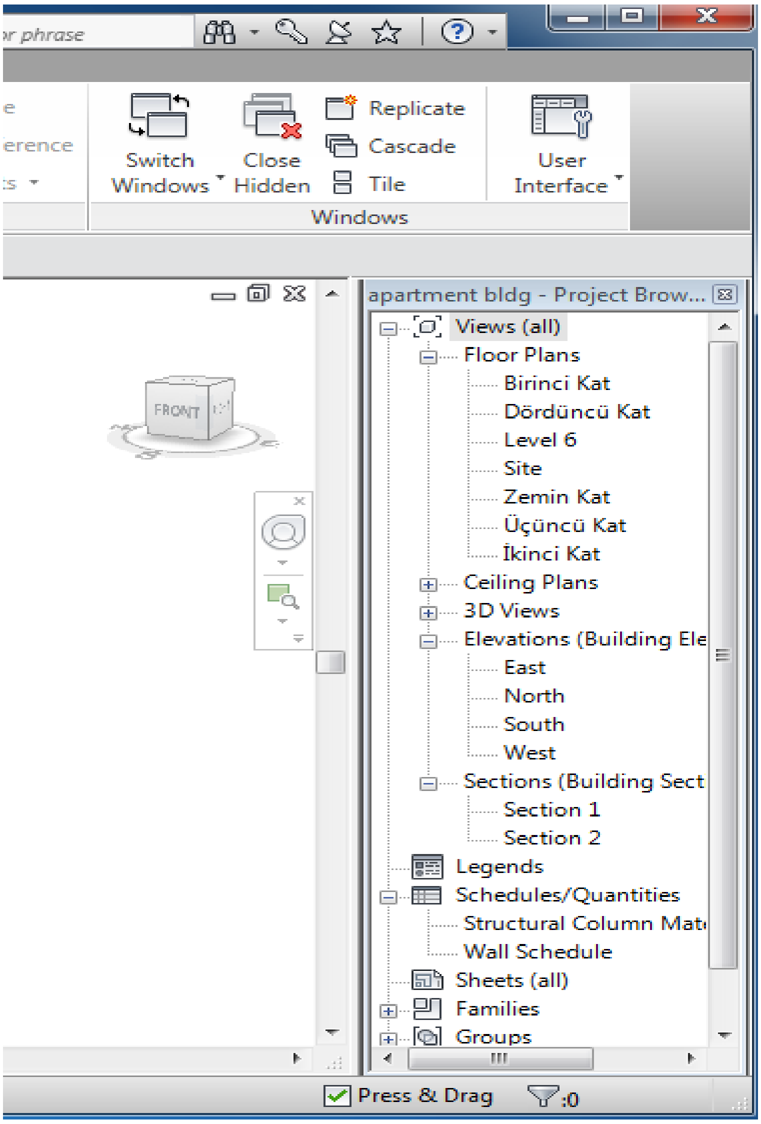

Figure 6. Project browser of Autodesk Revit Architecture 2011

Firstly, elevations from the project browser were used to generate building elevations according to the originally distributed architectural plans. Then, grids in floor plans were generated by selecting grid from home tab. Figure 6 shows the project browser that includes floor plans (Levels), ceiling plans, 3D views, elevations (East, north, south and west), sections, legends, schedules, sheets and etc for apartment project.

This drawing process was followed by generating the walls according to the originally distributed architectural plans. As it was mentioned above, wall can be drawn automatically by selecting wall from home tab. In this project, there were both 20cm and 10cm walls therefore materials and sizes of walls were adjusted from properties menu with the help of edit type option. Beside this, base constraint and top constraint of the walls can be adjusted from properties menu. Figure 7 below shows the simple wall drawing for level 1 and figure 8 shows the 3D view of walls that can be obtained automatically.

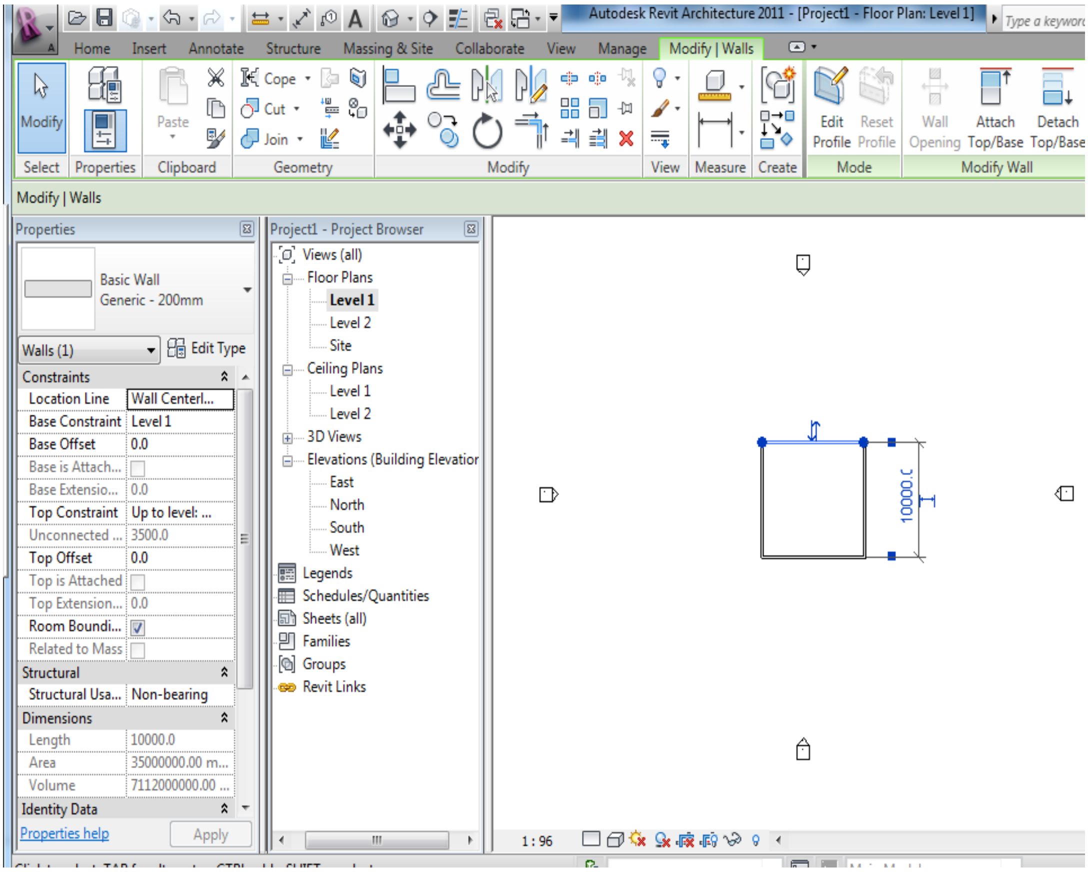

Figure 7. Floor plan that shows walls at level 1

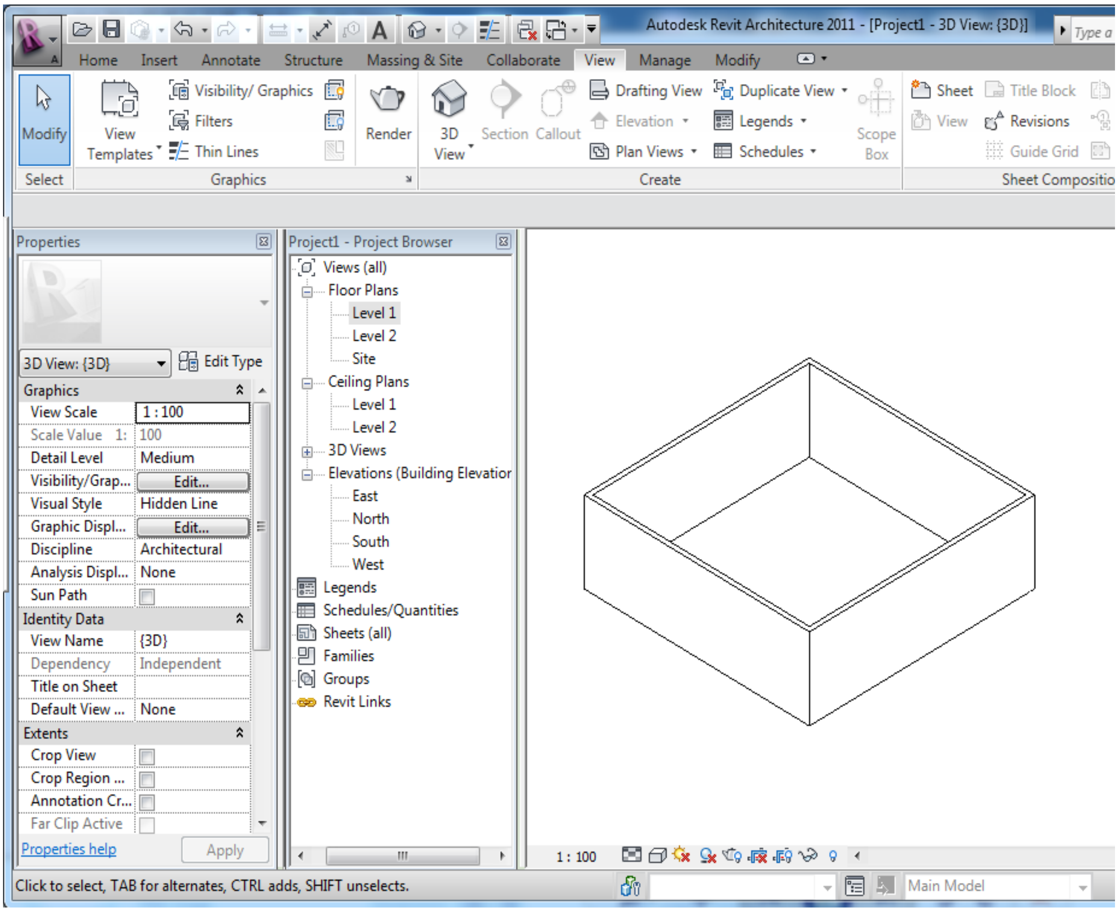

Figure 8. 3D view of the walls

Then, floors were added to the plan by selecting floor from home tab. When floor was generated at level 1, it could be copied to the other levels easily because when objects are needed to be copied to other levels, they can be automatically copied to the selected levels. Figure 9 below shows the floor example at level 1.

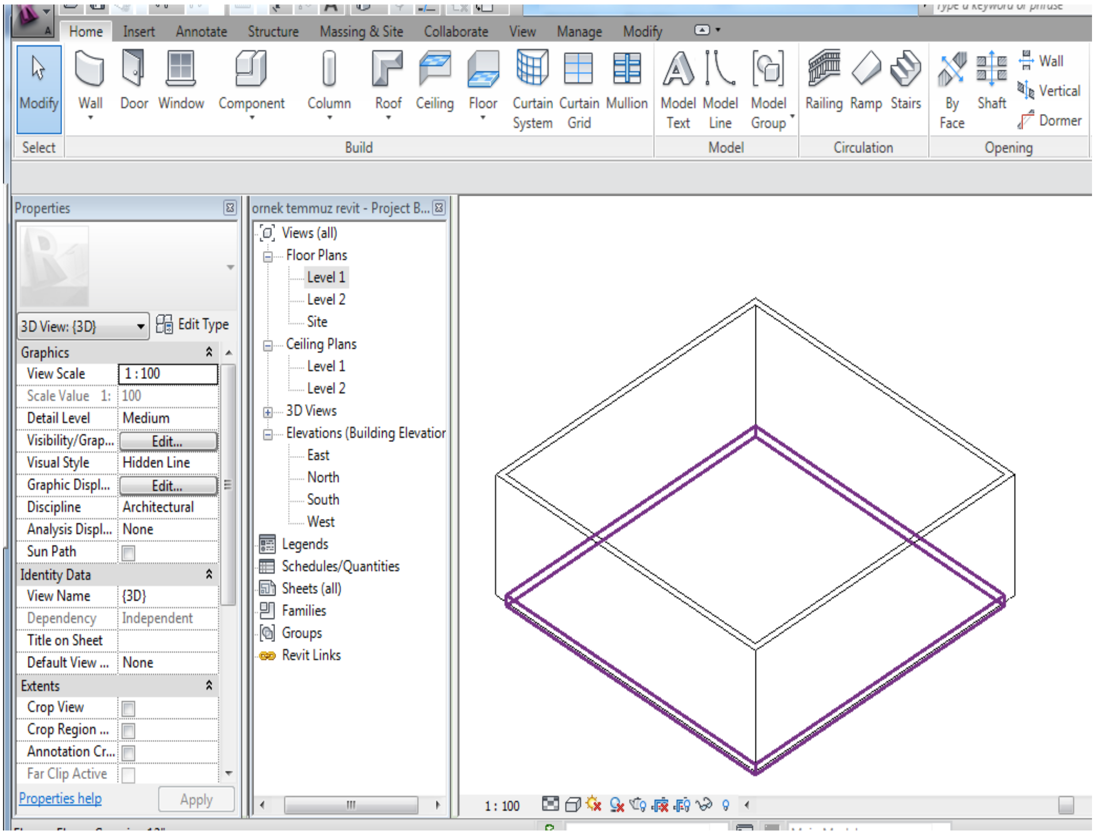

Figure 9. 3D view of walls and floor at level 1

Roof was also added to project by selecting roof from home tab and base levels, slopes, types could be adjusted from properties menu. Then, windows and doors were generated by selecting the types from library and by using the sizes according to the original architectural plan. Figure 10 shows the example of 3D view that includes walls, roof, floor, windows and door. Furthermore, the sections were also produced automatically without the need of drawing them manually.

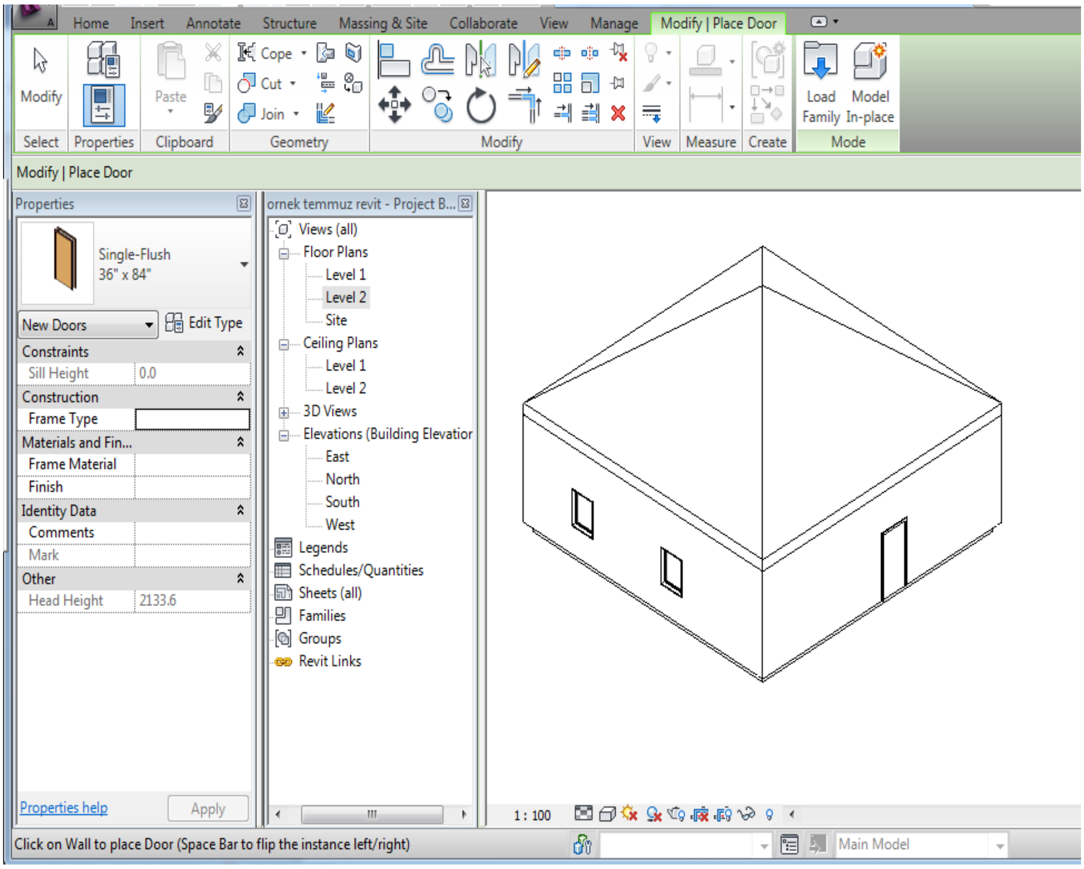

Figure 10. 3D view that includes walls, floor, roof, door and windows

Therefore, floor plans, 3D views, schedules and elevations were generated from project browser automatically with the help of its practicability. For example, with the just few clicks, north elevation was selected from project browser and north elevation of apartment building was automatically generated as it can be seen in figure 11.

However, unlike in Revit, in AutoCAD, floor plans, sections and views must be drawn manually. For example, north side view of the apartment building which was drawn in AutoCAD can be seen in figure 12. While the architects were drawing apartment building in Autodesk Revit Architecture, time was recorded again just like the one in AutoCAD.

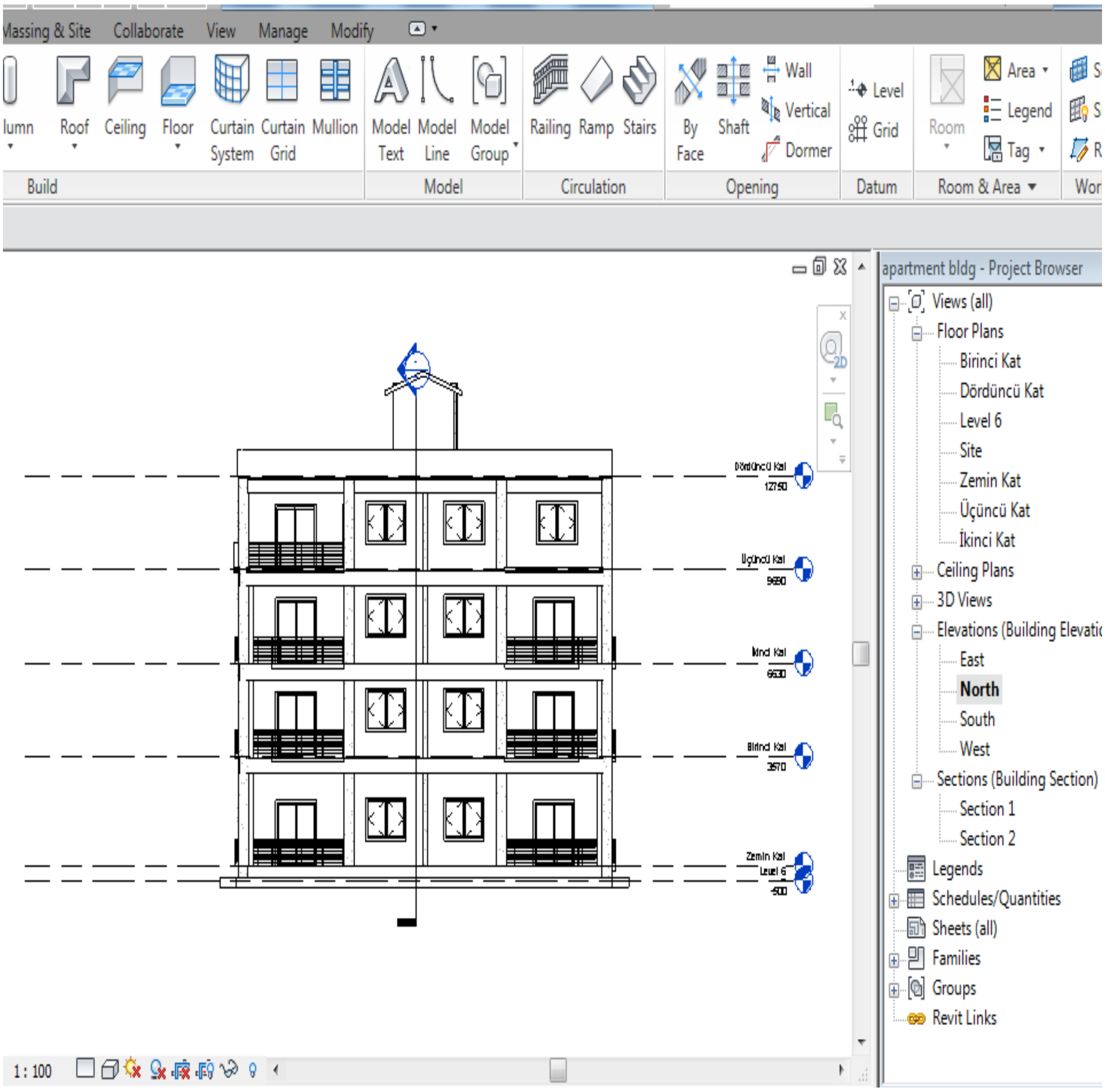

Figure 11. North side view of apartment building in Autodesk Revit Architecture

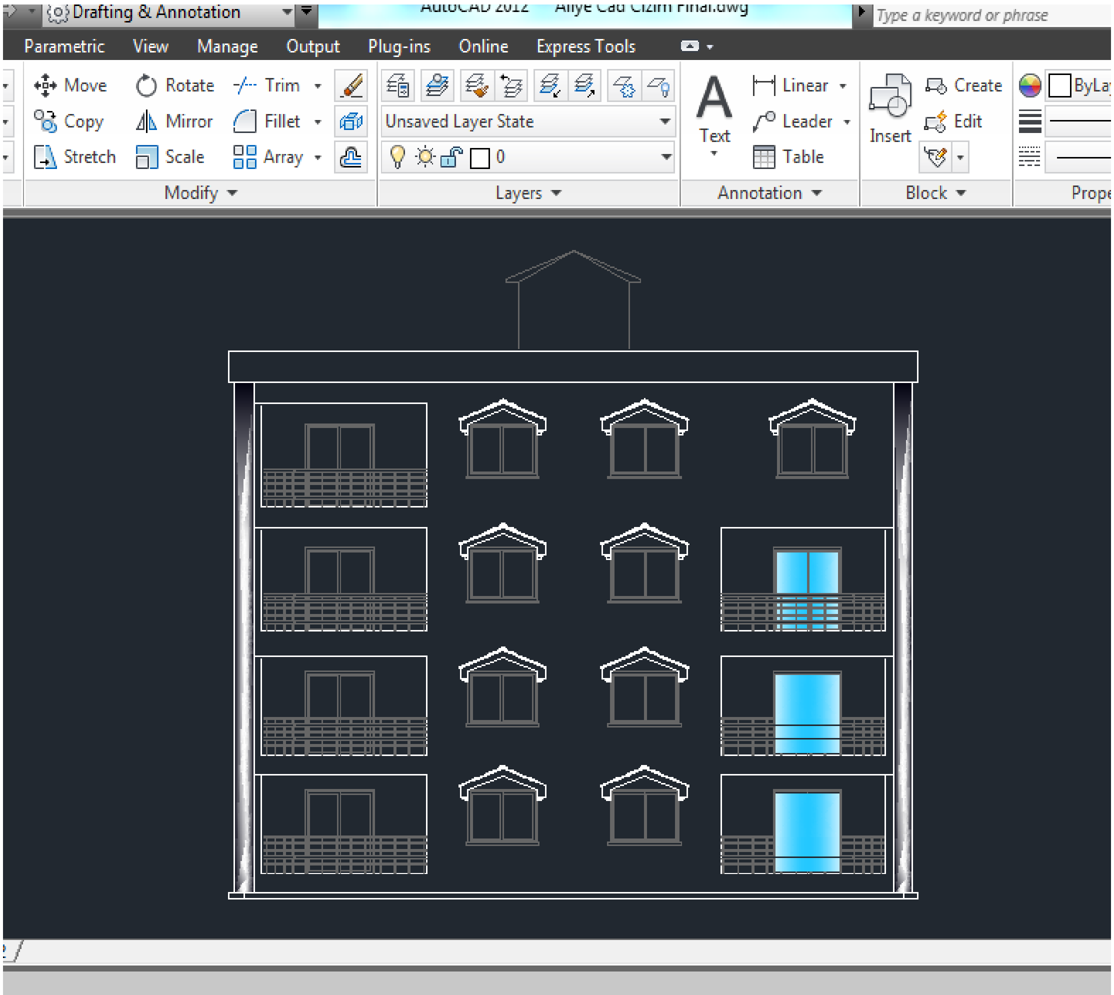

Figure 12. North side view of apartment building in AutoCAD

3.5 Calculation of Bill of Quantities

3.5.1 Manual Calculations

Bill of quantities defines the quantity of work which includes number, length, area, volume and weight by measuring each operation from the drawings and operations are classified according to trade or location within the work. Accuracy of results are very important so repetition in calculations should be prevented and every item should be measured, quantified and calculated accurately. Large works are divided into seperate groups and each group is subdivided into various trades such as plastering, painting, brick and etc. There is different letter prefix for each section (Çelik, 2007).

In this study, after project drawings were produced in AutoCAD, these drawings were used to calculate architectural bill of quantities by four civil engineers from construction industry. Therefore, the architectural drawings from AutoCAD that include plans, views and sections were distributed to four civil engineers as hardcopies to calculate architectural bill of quantities manually.

The format in Microsoft Excel was used to show architectural bill of quantity results that include item, description of work, number, dimension (length, width and height), unit and quantity. All works had the different letter prefix. Brickwork was shown with the letter prefix of A, plastering was B, painting was C, tiles and stairs were D and wood works were shown with the letter prefix of E.

Building elements such as doors, windows and related dimensions were counted and measured manually to obtain architectural bill of quantities. In plan, there were both 10 cm and 20cm walls so brickwork quantities were calculated separately for both

10cm and 20cm walls except one engineer. Wall lengths were measured from floor plans and heights were measured from sections manually to obtain the area of walls. Then, the areas of windows and doors which were existed on the walls were subtracted to obtain total brickwork quantity. Since measurements were obtained manually, extra caution was taken so that each wall was not counted twice to prevent errors in calculations.

Then, internal and external areas of walls in the building were calculated seperately for plaster and painting quantities. The areas of walls were calculated by measuring related length and height from floor plans and sections manually. After finding total areas of the walls, again the areas of the windows and doors that were counted and calculated one by one were subtracted from the whole area of walls to obtain total plastering amount.

In addition, floor areas of all rooms were calculated seperately by measuring room dimensions manually. Firstly, total floor area of rooms and balconies on the ground floor was calculated and it was multiplied by three because the ground floor, first floor and the second floor all have the same plan. Then, third floor area and area of balconies at third floor were calculated manually and the area was added to the total area of other three floors to obtain the total floor area of whole building.

This manual calculation process was a very time consuming. Table 1 below gives the details about calculation durations of brickwork, plaster and painting and floor areas in terms of minutes. In addition, the detailed architectural bill of quantities that were calculated by four civil engineers are provided also at Table 2, 3, 4 and 5.

Table 1. Duration of architectural bill of quantity calculations in terms of minutes

Item	Description of Work	Duration (Min)			
		Civil Eng. (1)	Civil Eng. (2)	Civil Eng. (3)	Civil Eng. (4)
A	Brickwork	72	64	57	66
B&C	Plaster/Painting	112	71	68	92
D	Floor Tiles	36	25	21	29

Table 2. Manually calculated architectural bill of quantities civil engineer (1)

Item	Description of Work	#	Dimension			Unit	Quantity		
			Length	Width	Height		(+)	(-)	Total
A	**Brickwork**								
A1	20cm Brick	3	200.3		1.00	m^2		55.8	433.4
	20cm Brick	1	180.8		1.00	m^2		47.1	133.7
	20cm Brick	1	25.5		1.00	m^2		12.5	13.0
	20cm Brick	1	199.1		1.00	m^2		16.9	182.2
A2	10cm Brick	3	182.9		1.00	m^2		33.7	447.4
	10cm Brick	1	195.6		1.00	m^2		39.2	156.4
									1366.1
B	**Painting**								
B1	Internal Painting	6	118.77		2.91	m^2		24.865	1924.5
		1	14.09		2.91	m^2		4.6	36.5
		2	14.09		2.91	m^2		10.8	60.3
		1	211.80		2.91	m^2		84.7	531.66
		1	14.09		2.50	m^2	11.4	12.4	34.21
B2	External Painting	1	15.8		2.91	m^2		12.4	33.6
		1	270.5		2.91	m^2		165.9	621.3
		1	92.5		2.91	m^2		48.0	221.1
		1	112.0		1.00	m^2			112.0
		6	8.3		1.00	m^2			49.8
									3625.0
C	**Plastering**								
C1	Internal Painting	6	118.77		2.91	m^2		24.865	1924.5
		1	14.09		2.91	m^2		4.6	36.5
		2	14.09		2.91	m^2		10.8	60.3
		1	211.80		2.91	m^2		84.7	531.66
		1	14.09		2.50	m^2	11.4	12.4	34.21
C2	External Painting	1	15.8		2.91	m^2		12.4	33.6
		1	270.5		2.91	m^2		165.9	621.3
		1	92.5		2.91	m^2		48.0	221.1

		1	112.0		1.00	m^2			112.0
		6	8.3		1.00	m^2			49.8
									3625.0
D	**Tiles**								
D1	Floor Tiles	3	226.98		1.00	m^2			680.9
		1	245.97		1.00	m^2			246.0
									926.9
D2	Stairs	4	17			pcs			68
E	**Wood Works**								
E1	Doors								
	180*220	8				pcs			8
	95*220	13				pcs			13
	90*220	26				pcs			26
	100*220	18				pcs			18
	215*220	7				pcs			7
	165*197	1				pcs			1
	180*210	5				pcs			5
	200*220	3				pcs			3
	95*210	1				pcs			1
	90*210	1				pcs			1
	80*220	1				pcs			1
	160*210	3				pcs			3
	160*220	3				pcs			3
E2	Windows								
	180*130	17		1.8	1.3	m2			39.78
	100*130	11		1	1.3	m2			14.3
	200*130	7		2	1.3	m2			18.2
	65*65	14		0.65	0.65	m2			5.915
	160*130	16		1.6	1.3	m2			33.28
	75*636	4		0.75	6.36	m2			19.08
	150*130	2		1.5	1.3	m2			3.9
	190*130	1		1.9	1.3	m2			2.47
	75*220	1		0.75	2.2	m2			1.65
	75*445	2		0.75	4.45	m2			6.675
	60*60	1		0.6	0.6	m2			0.36
									145.6

Table 3. Manually calculated architectural bill of quantities by civil engineer (2)

Item	Description of Work	#	Dimension			Unit	Quantity		
			Length	Width	Height		(+)	(-)	Total
A	**Brickwork**								
A1	20cm Brick	6	6.9		2.91	m^2		5.3	89.4
	20cm Brick	6	31.3		2.56	m^2		22.6	345.0
	20cm Brick	1	43.3		2.56	m^2		7.2	103.7
	20cm Brick	2	6.4		2.56	m^2		9.5	13.7
	20cm Brick	1	55.8		1.00	m^2			55.8
	20cm Brick	1	2.0		2.91	m^2		1.3	4.6
	20cm Brick	1	68.5		2.56	m^2		45.0	130.2
	20cm Brick	1	12.9		2.00	m^2		12.4	13.5
A2	10cm Brick	6	11.7		2.91	m^2		6.1	168.0
	10cm Brick	6	22.3		2.56	m^2		10.9	277.6
	10cm Brick	1	20.3		2.91	m^2		10.1	48.9
	10cm Brick	1	40.3		2.56	m^2		30.0	73.2
	10cm Brick	1	32.6		1.00	m^2			32.6
									1356.3
B	**Painting**								
B1	Internal Painting	2	120.2		2.91	m^2		40.1	619.2
		1	14.1		2.91	m^2		9.0	32.0
		4	120.2		2.91	m^2		40.1	1238.3
		2	14.1		2.91	m^2		15.2	51.5
		1	191.4		2.91	m^2		79.8	477.3
		1	14.1		2.91	m^2		8.9	32.1
		1	14.1		2.50	m^2		12.4	22.9
B2	External Painting	1	72.9		2.91	m^2		52.9	159.3
		3	8.8		2.91	m^2		4.0	64.7
		2	72.9		2.91	m^2		59.2	305.9
		1	81.7		2.91	m^2		51.9	185.7
		2	63.5		1.00	m^2			127.0
		1	15.8		2.50	m^2		12.4	27.1
		1	63.8		1.00	m^2			63.8
									3406.7
C	**Plastering**								
	Internal Painting	2	120.2		2.91	m^2		40.09	619.16
		1	14.1		2.91	m^2		8.95	32.02
		4	120.2		2.91	m^2		40.09	1238.32
		2	14.1		2.91	m^2		15.24	51.47
		1	191.4		2.91	m^2		79.75	477.25
		1	14.1		2.91	m^2		8.88	32.10
		1	14.1		2.50	m^2		12.38	22.86
	External Painting	1	72.9		2.91	m^2		52.91	159.26
		3	8.8		2.91	m^2		4.03	64.73
		2	72.9		2.91	m^2		59.20	305.94

		1	81.7		2.91	m^2		51.90	185.70
		2	63.5		1.00	m^2			127.00
		1	15.8		2.50	m^2		12.38	27.13
		1	63.8		1.00	m^2			63.76
									3406.7
D	**Tiles**								
D1	Floor Tiles	3	221.4		1.00	m^2			664.1
		1	245.1		1.00	m^2			245.1
									909.1
D2	Stairs	4	17			pcs			68
E	**Wood Works**								
E1	Doors								
	180*220	8				pcs			8
	95*220	13				pcs			13
	90*220	26				pcs			26
	100*220	18				pcs			18
	215*220	7				pcs			7
	165*197	1				pcs			1
	180*210	5				pcs			5
	200*220	3				pcs			3
	95*210	1				pcs			1
	90*210	1				pcs			1
	80*220	1				pcs			1
	160*210	3				pcs			3
	160*220	3				pcs			3
E2	Windows								
	180*130	17		1.8	1.3	m^2			39.78
	100*130	11		1	1.3	m^2			14.3
	200*130	7		2	1.3	m^2			18.2
	65*65	14		0.65	0.65	m^2			5.915
	160*130	16		1.6	1.3	m^2			33.28
	75*636	4		0.75	6.36	m^2			19.08
	150*130	2		1.5	1.3	m^2			3.9
	190*130	1		1.9	1.3	m^2			2.47
	75*220	1		0.75	2.2	m^2			1.65
	75*445	2		0.75	4.45	m^2			6.675
	60*60	1		0.6	0.6	m^2			0.36
									145.6

Table 4. Manually calculated architectural bill of quantities by civil engineer (3)

Item	Description of Work	#	Dimension			Unit	Quantity		
			Length	Width	Height		(+)	(-)	Total
A	**Brickwork**								
A1 A2	20cm&10cm Brick	3.0	319.6		1.00	m^2			958.8
		3.0	16.7		1.00	m^2			50.1
		1.0	33.1		1.00	m^2		6.2	26.9
		1.0	310.7		1.00	m^2			310.7
									1346.5
B	**Painting**								
B1 B2	Internal & External	3.0	893.7		1.00	m^2		92.4	2404.0
		3.0	111.3		1.00	m^2		4.6	320.3
		1.0	84.3		1.00	m^2		6.2	78.1
		3.0	28.8		1.00	m^2			86.3
		1.0	807.7		1.00	m^2			807.7
									3696.3
C	**Plastering**								
C1 C2	Internal & External	3.0	893.7		1.00			92.4	2404.0
		3.0	111.3		1.00	m^2		4.6	320.3
		1.0	84.3		1.00	m^2		6.2	78.1
		3.0	28.8		1.00	m^2			86.3
		1.0	807.7		1.00	m^2			807.7
									3696.3
D	**Tiles**								
D1	Floor Tiles	3.0	233.6		1.00	m^2			700.7
		1.0	239.5		1.00	m^2			239.5
									940.2
D2	Stairs	4.0	17.0			pcs			68.0
E	**Wood Works**								
E1	Doors								
	90*220	26.0				pcs			26.0
	95*220	13.0				pcs			13.0
	100*220	18.0				pcs			18.0
	165*197	1.0				pcs			1.0
	90*210	1.0				pcs			1.0
	180*210	5.0				pcs			5.0
	95*210	1.0				pcs			1.0
	200*220	3.0				pcs			3.0
	215*220	7.0				pcs			7.0
	80*220	1.0				pcs			1.0
	180*220	8.0				pcs			8.0
	160*210	3.0				pcs			3.0
	160*220	3.0				pcs			3.0
E2	Windows								
	180*130	17.0		1.8	1.3	m^2			39.8

	160*130	16.0		1.6	1.3	m^2			33.3
	100*130	11.0		1.0	1.3	m^2			14.3
	200*130	7.0		2.0	1.3	m^2			18.2
	65*65	14.0		0.7	0.7	m^2			5.9
	190*130	1.0		1.9	1.3	m^2			2.5
	75*220	1.0		0.8	2.2	m^2			1.7
	75*445	2.0		0.8	4.5	m^2			6.7
	60*60	1.0		0.6	0.6	m^2			0.4
	150*130	2.0		1.5	1.3	m^2			3.9
	75*636	4.0		0.8	6.4	m^2			19.1
									145.6

Table 5. Manually calculated architectural bill of quantities by civil engineer (4)

Item	Description of Work	#	Dimension			Unit	Quantity		
			Length	**Width**	**Height**		**(+)**	**(-)**	**Total**
A	**Brickwork**								
A1	20cm Brick	3	14.2		2.91	m^2		10.5	92.2
	20cm Brick	3	81.8		2.56	m^2		34.8	524.1
	20cm Brick	3	11.0		2.56	m^2		4.6	71.2
	20cm Brick	1	69.4		2.56	m^2		47.0	130.8
	20cm Brick	1	2.8		2.91	m^2	18.0	1.3	24.8
	20cm Brick	1	54.8		1.00	m^2			54.8
A2	10cm Brick	3	23.4		2.91	m^2		12.1	168.2
	10cm Brick	3	40.9		2.56	m^2		26.0	236.1
	10cm Brick	1	16.3		2.91	m^2		10.1	37.2
	10cm Brick	1	42.4		2.56	m^2		28.0	80.5
	10cm Brick	1	21.9		1.00	m^2			21.9
									1442
B	**Painting**								
B1	Internal Painting	3	243.0		2.91	m^2		96.7	1830.9
		1	200.9		2.91	m^2		86.4	498.1
B2	External Painting	3	89.7		3.06	m^2		58.5	648.0
		1	162.8		1.00	m^2			162.8
		1	81.7		3.06	m^2	57.9	48.0	259.9
									3399.7
C	**Plastering**								
C1	Internal Plastering	3	243.0		2.91	m^2		96.7	1830.9
		1	200.9		2.91	m^2		86.4	498.1
C2	External Plastering	3	89.7		3.06	m^2		58.5	648.0
		1	162.8		1.00	m^2			162.8

		1	81.7		3.06	m^2	57.9	48.0	259.9
									3399.7
D	**Tiles**								
D1	Floor Tiles	3	248.7		1.00	m^2		5.3	730.2
		1	249.3		1.00	m^2			249.3
									979.5
D2	Stairs	4	17			pcs			68
E	**Wood Works**								
E1	Doors								
	90*220	26				pcs			26
	95*220	13				pcs			13
	100*220	18				pcs			18
	165*197	1				pcs			1
	90*210	1				pcs			1
	180*210	5				pcs			5
	95*210	1				pcs			1
	200*220	3				pcs			3
	215*220	7				pcs			7
	80*220	1				pcs			1
	180*220	8				pcs			8
	160*210	3				pcs			3
	160*220	3				pcs			3
E2	Windows								
	180*130	17		1.8	1.3	m^2			39.8
	160*130	16		1.6	1.3	m^2			33.3
	100*130	11		1	1.3	m^2			14.3
	200*130	7		2	1.3	m^2			18.2
	65*65	14		0.65	0.65	m^2			5.9
	190*130	1		1.9	1.3	m^2			2.5
	75*220	1		0.75	2.2	m^2			1.7
	75*445	2		0.75	4.45	m^2			6.7
	60*60	1		0.6	0.6	m^2			0.4
	150*130	2		1.5	1.3	m^2			3.9
	75*636	4		0.75	6.36	m^2			19.1
									145.6

Table 6. Summary of manually calculated architectural bill of quantities by four civil engineers

Item	Description of Work	Unit	Quantity			
			Civil Eng. (1)	**Civil Eng. (2)**	**Civil Eng. (3)**	**Civil Eng. (4)**
A	Brickworks	m^2	1366.1	1356.3	1346.5	1442
B	Plastering (1coat)	m^2	3625	3406.7	3696.3	3399.7
C	Painting	m^2	3625	3406.7	3696.3	3399.7
D	Floor Tiles	m^2	926.9	909.1	940.2	979.5

3.5.2 Quantity Takeoff with BIM

Automatical extraction of quantities from the model is among many benefits of BIM. Autodesk Revit Architecture can generate schedule and material quantities of the model and Autodesk Quantity Takeoff which is a cost estimating and quantity surveying software can also be used to obtain architectural bill of quantities.

Autodesk Quantity Takeoff can provide quantities automatically in just few minutes by exporting model from Autodesk Revit Architecture to Autodesk Quantity Takeoff because it can count building components and measure areas automatically and quickly. Results can be analyzed in workbook menu and it can be also used for material cost estimating purposes (www.autodesk.com).

3.5.2.1 Quantity Takeoff with Autodesk Revit Architecture

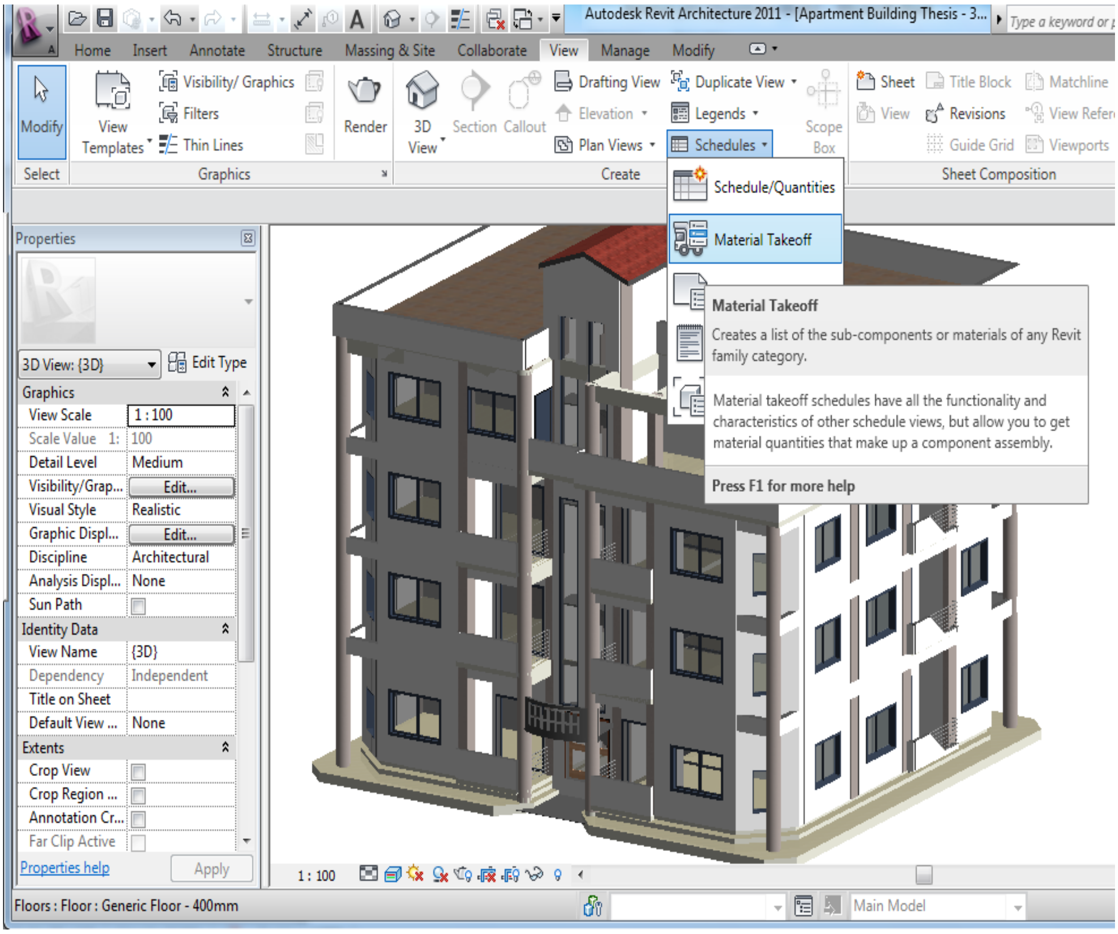

Figure 13. Material takeoff tool of Autodesk Revit Architecture

Figure 13 shows the model in Autodesk Revit Architecture. Material Takeoff which is at view tab can be selected to generate quantity takeoff of the building model. Then from the fields at material takeoff properties, family and type, material name and material area were selected to be added to scheduled fields according to the order as can be seen in figure 14. Then, fields were sorted by material name and then sorted by family& type as in figure 15. In addition, from formatting, some format changes were done. For example, for material area, calculate total was selected as in figure 16. Then the material takeoff list of the all building elements as in figure 17 was generated automatically in 1 minute. Table 7 summarizes the results of architectural bill of quantities that were generated automatically from Autodesk Revit Architecture.

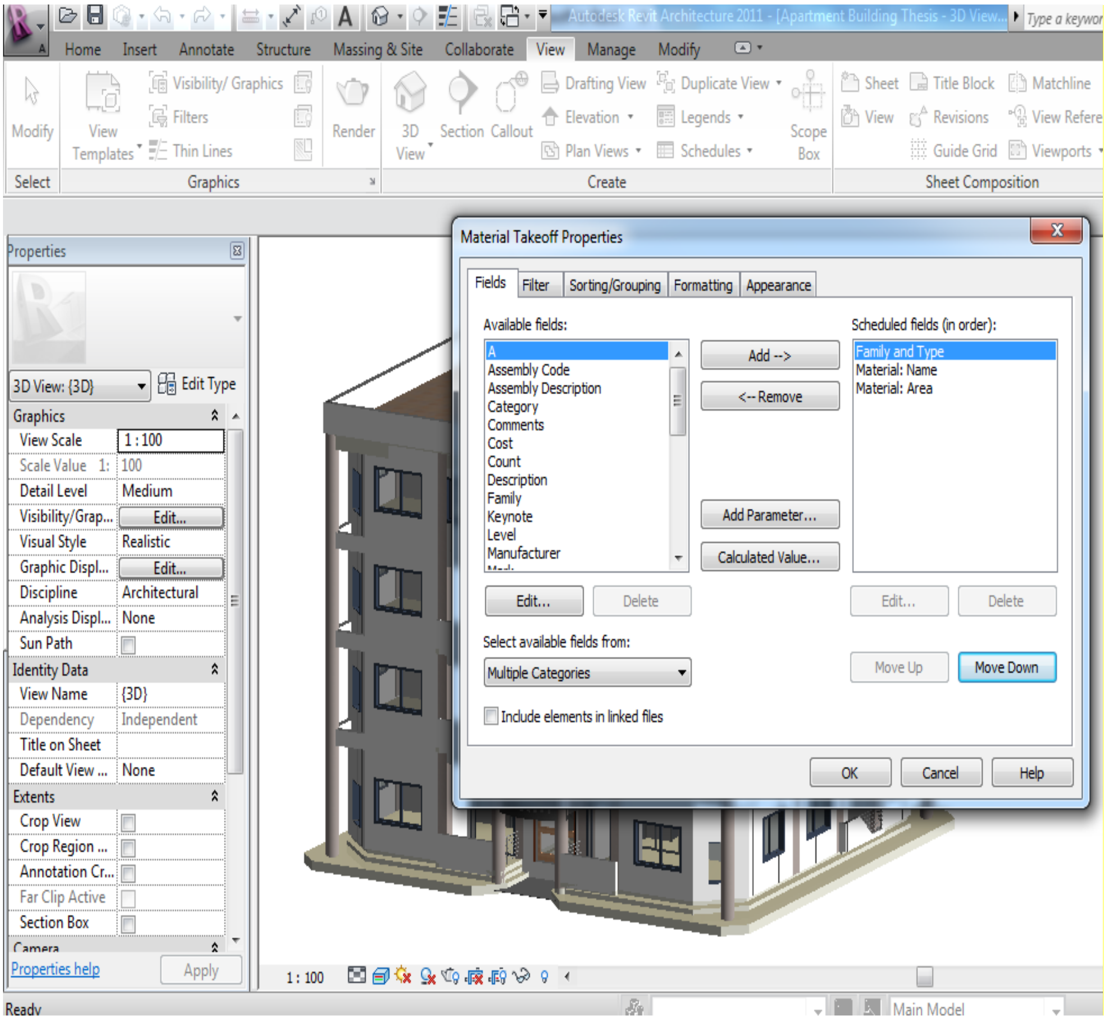

Figure 14. Material takeoff properties menu (Fields part)

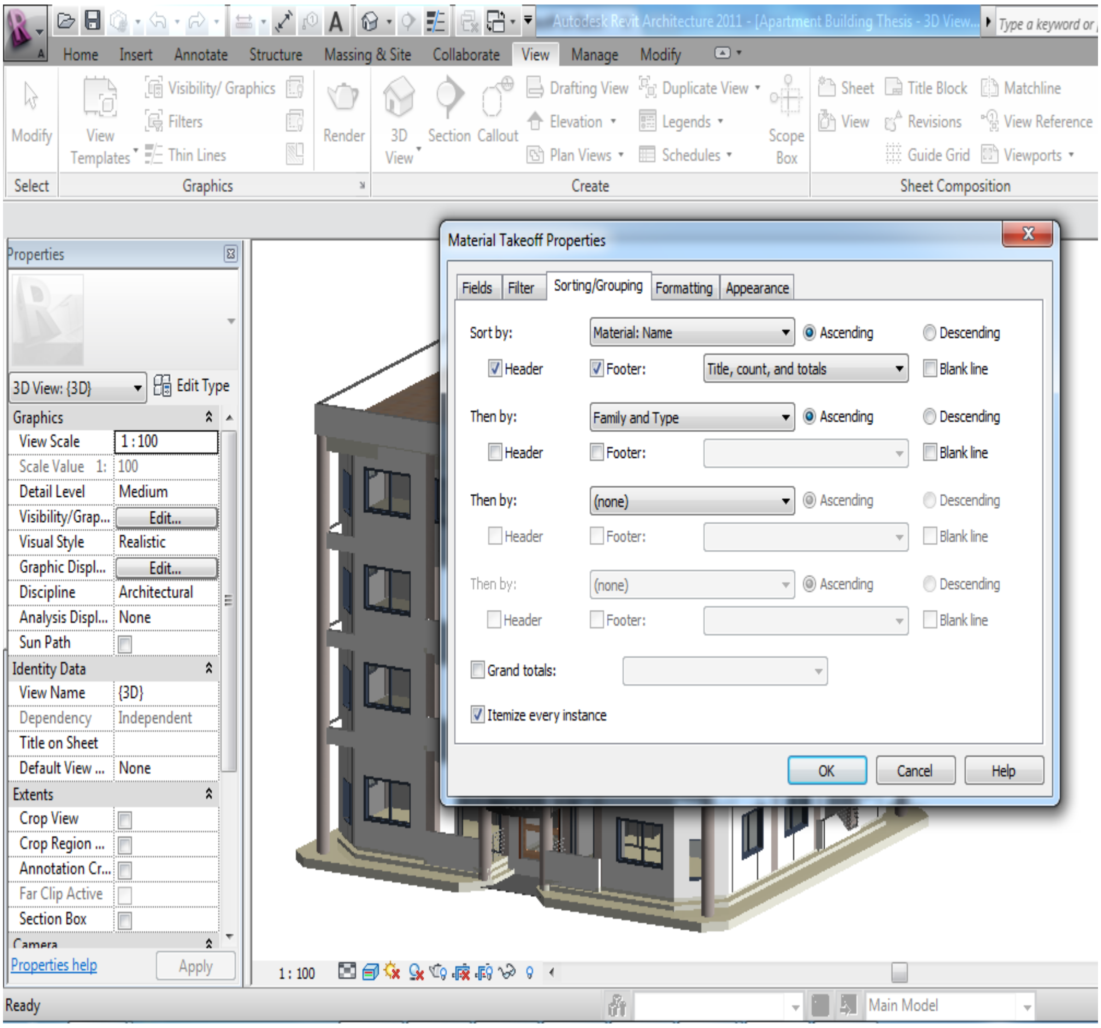

Figure 15. Material takeoff properties menu (sorting/grouping)

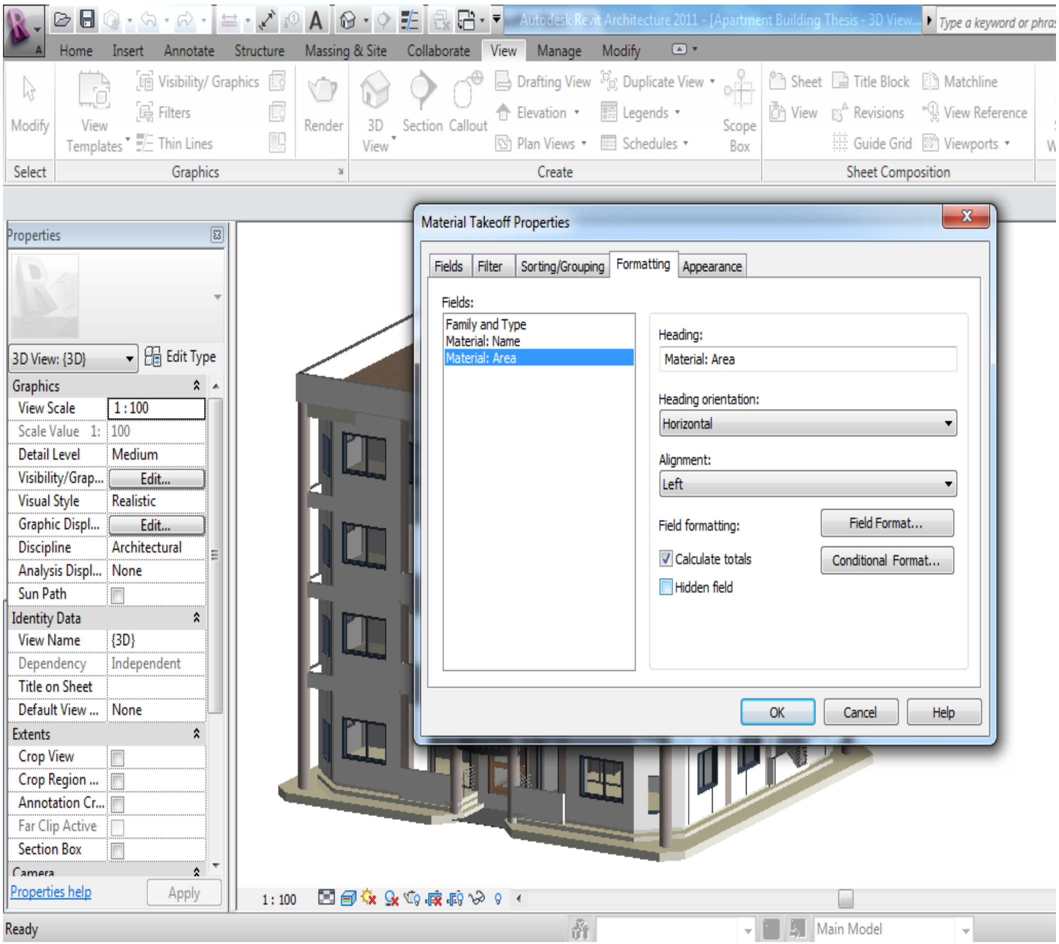

Figure 16. Material takeoff properties menu (formatting)

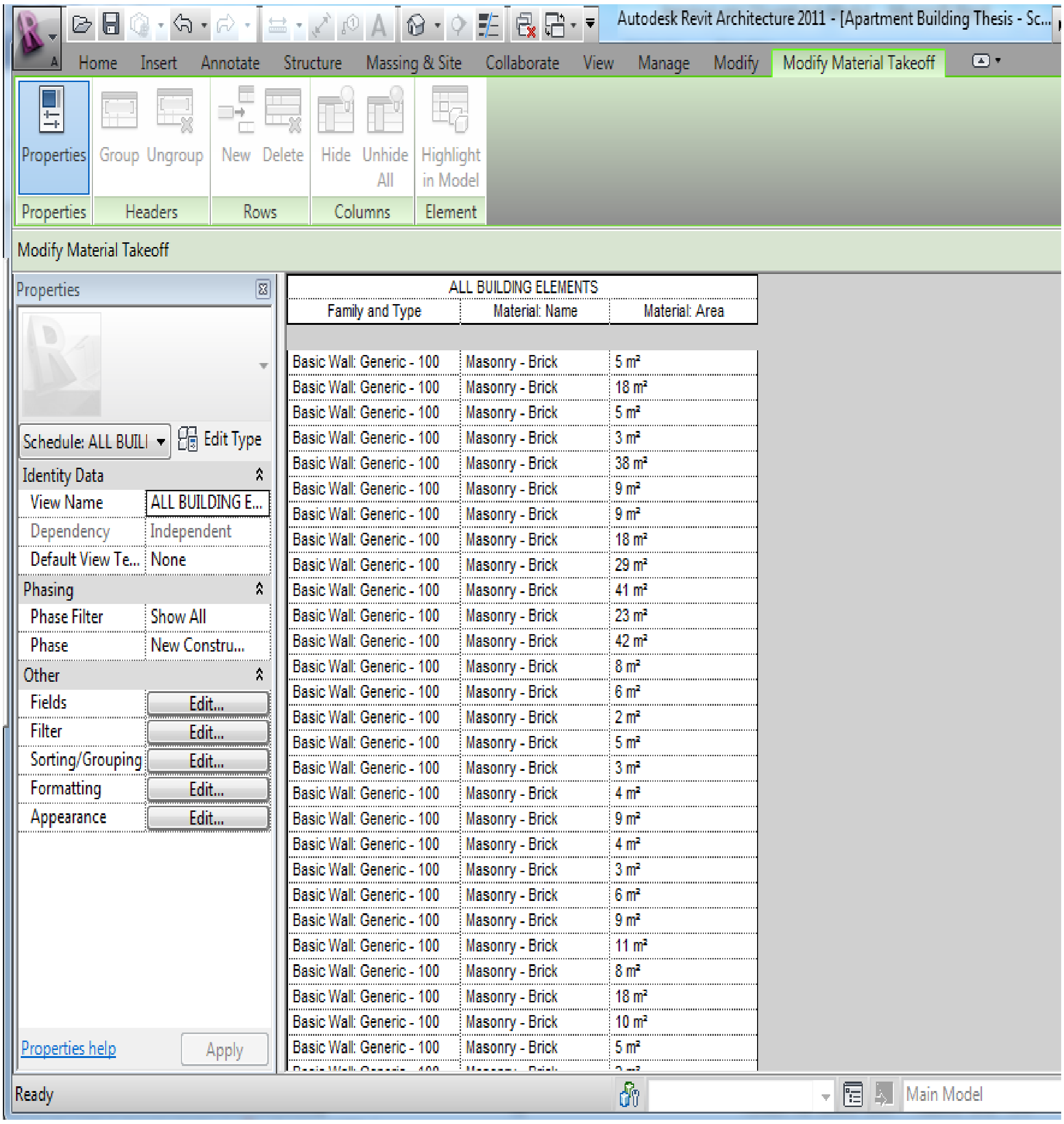

Figure 17. Material takeoff list that shows brick quantities of the walls

Table 7. Architectural bill of quantities that was generated automatically from Autodesk Revit Architecture

Item	**Description of Work**	**Unit**	**Quantity**
A	Brickworks	m^2	1688
B	Plastering (1coat)	m^2	3554
C	Painting	m^2	3554
D	Floor Tiles	m^2	1005

3.5.2.2 Quantity Takeoff with Autodesk Quantity Takeoff

Model which is generated in Autodesk Revit Architecture can be exported to Autodesk Quantity Takeoff to obtain bill of quantities. Therefore, architectural bill of quantities can be extracted from model automatically with Autodesk Quantity Takeoff and takeoffs can be modified according to user preference. Therefore, architectural model generated in Autodesk Revit Architecture was exported into Autodesk Quantity Takeoff as shown in figure 18 by selecting all views and sheets in the model and figure 19 shows the model in Autodesk Quantity Takeoff.

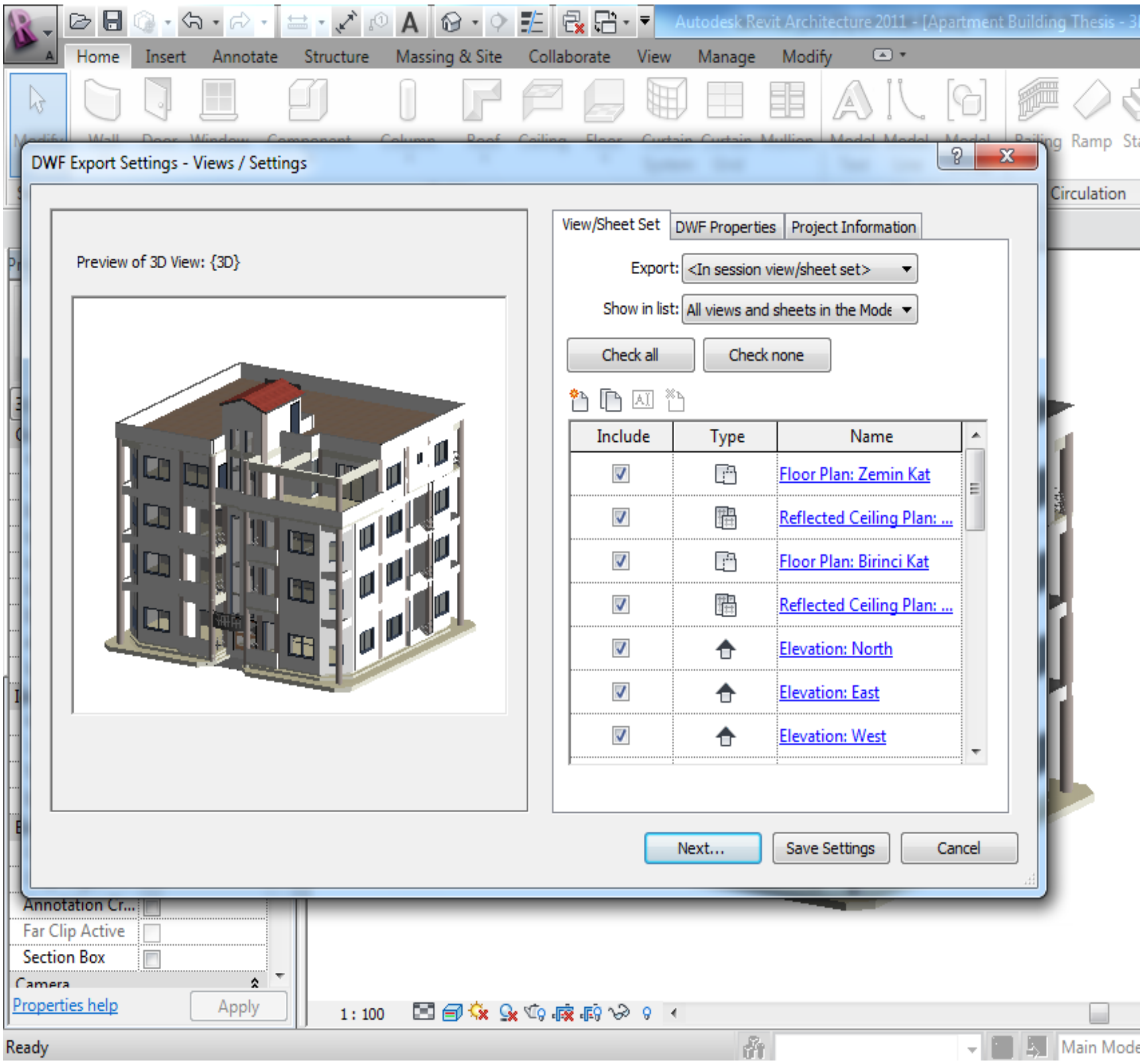

Figure 18. Exporting of model from Autodesk Revit Architecture into Autodesk Quantity Takeoff

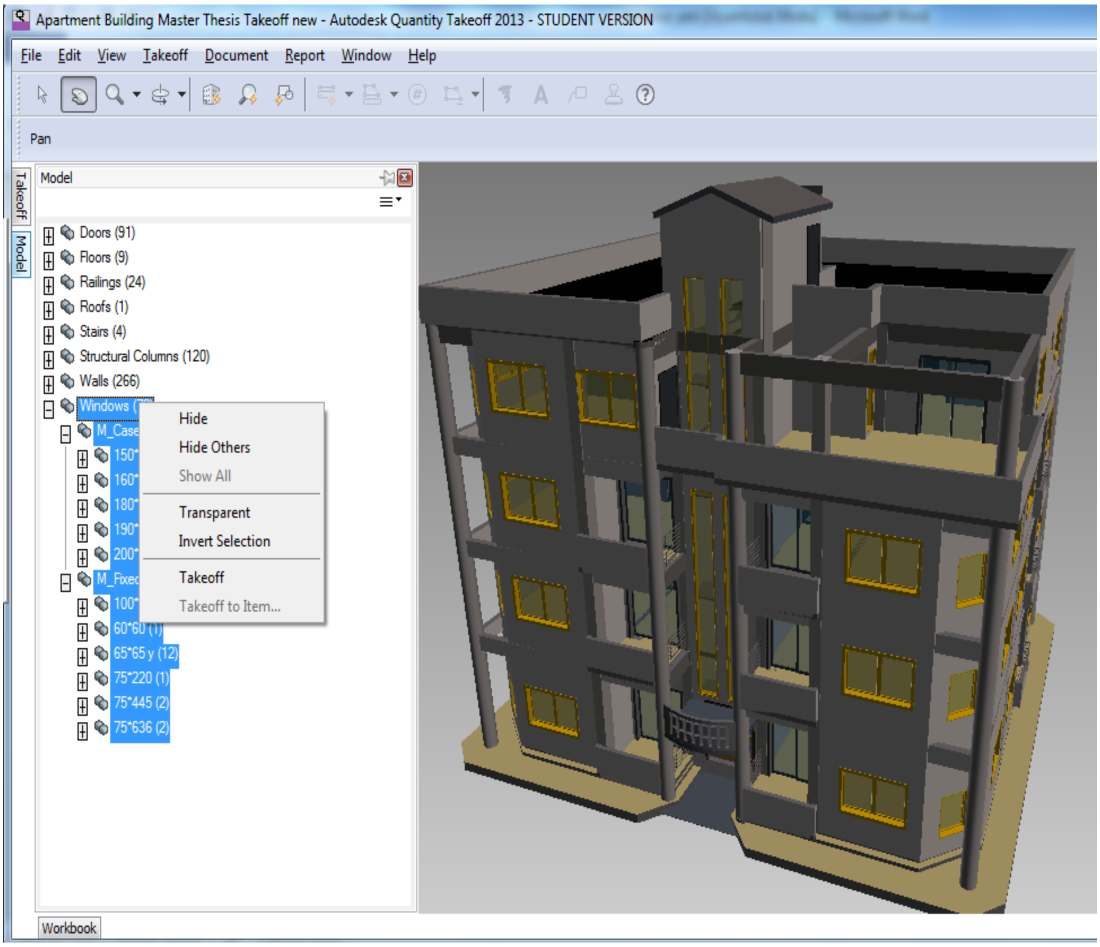

Figure 19. 3D model in Autodesk Quantity Takeoff

Model includes all objects exist in the building such as doors, floors, railings, roofs, stairs, structural columns, walls and windows. When any building object is selected, it can be coloured in the model. For example, when windows were selected in model, all window types in the model were listed and coloured with yellow as in figure 19. Then all selected window types can be taken off easily. Therefore, quantities of building were extracted in 1 minute and each extracted components in the building were coloured with different colours as in figure 20 and all components that were extracted for takeoff were listed in the takeoff menu. Due to practicability of the software, unit types of each component such as area and volume which were needed for takeoff were also adjusted. For example, unit type of walls was adjusted as area for brickwork quantity and when floor was extracted for takeoff, type was adjusted to area to obtain total floor areas.

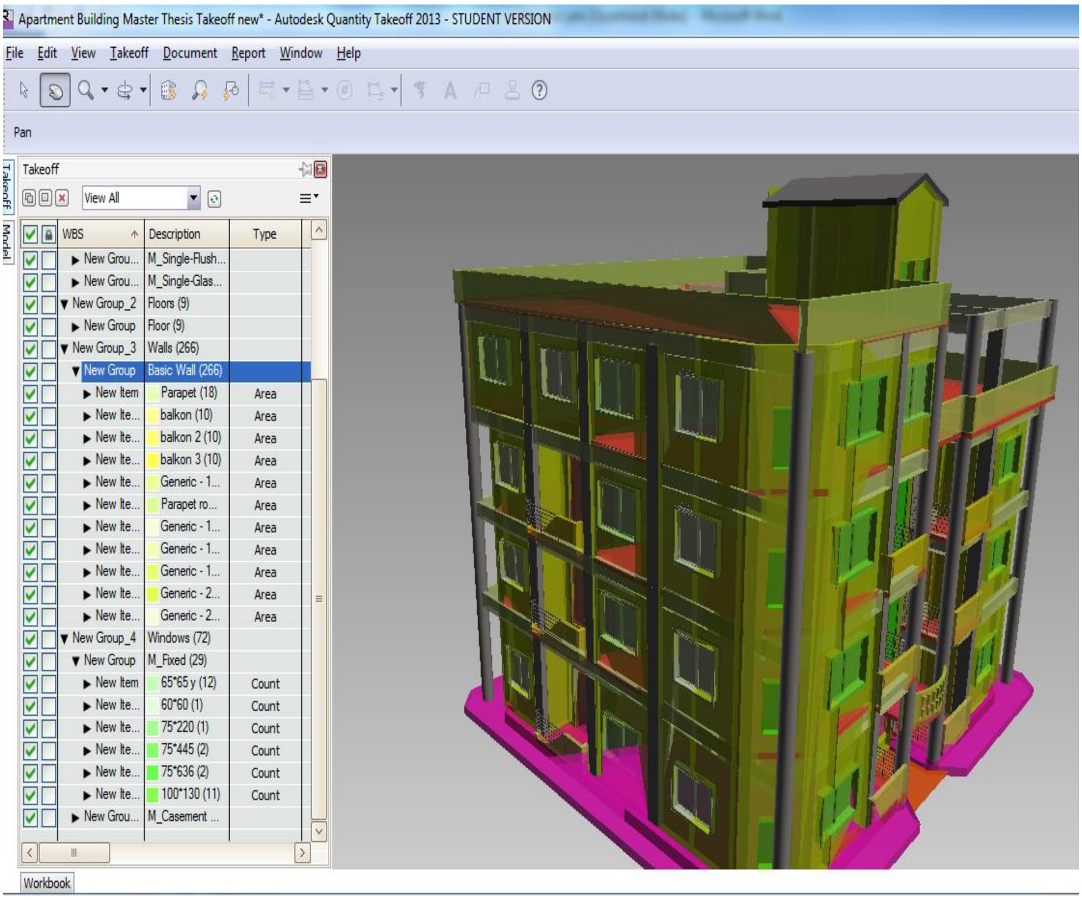

Figure 20. Different colours of extracted quantities and takeoff menu of Autodesk Quantity Takeoff

Moreover, number of doors and windows were obtained automatically without the need of counting them one by one. Therefore, after type of quantities was adjusted according to the units, all extracted quantities were listed in workbook menu as in figure 21.

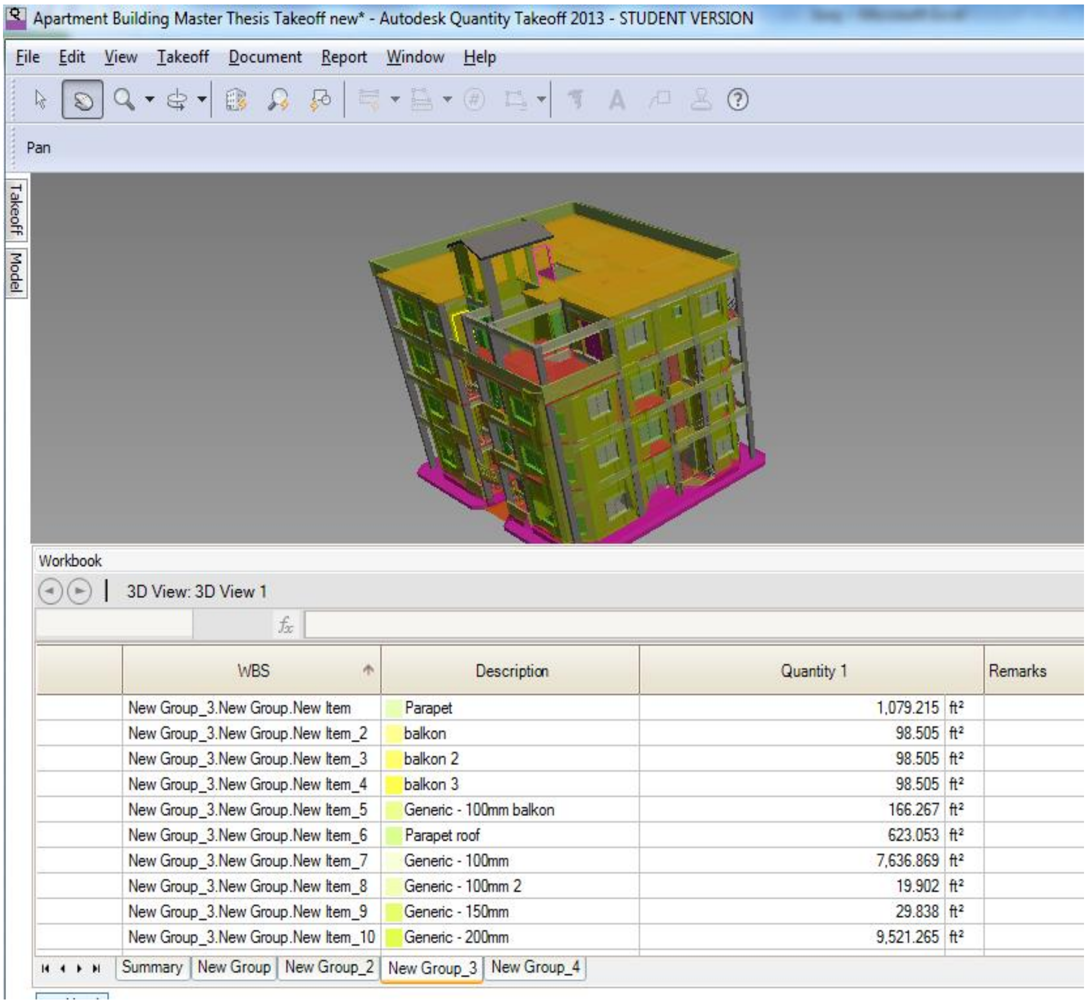

Figure 21. Workbook menu of Autodesk Quantity Takeoff

Therefore, Table 8 below summarizes brickwork and floor quantities in terms of area that were extracted from Autodesk Quantity Takeoff.

Table 8. Summary of bill of quantities extracted from Autodesk Quantity Takeoff

Item	Description of Work	Unit	Quantity
A	Brickworks	m^2	1696
D	Floor Tiles	m^2	1004.3

3.6 Comparison of 4D BIM Models and Microsoft Project

3.6.1 Microsoft Project

It is project management software and it is used for construction planning. By defining activities, their durations and relationships between works, time schedules can be obtained.

3.6.2 4D BIM

4D BIM model is the integration of 3D BIM model and project planning software. 4D BIM models provide many advantages such as better project planning, 4D visualization, better communication between project parties, better team coordination, better understanding of construction sequence, visualization of time constraints in project, improved productivity and quality improved delivery time, time and cost savings.

There are different kind of 4D BIM softwares such as Autodesk Naviswork, Synchro Professional, Virtual Office 4D Manager by Vico Software, Tekla Structures, Bentley Navigator and Visual Simulation by Innovaya.

3.6.2.1 Autodesk Naviswork

After schedule is produced in project planning software, it can be imported in Autodesk Naviswork and tasks can be linked with building objects due to automatic linking option to obtain construction sequences. With the using of timeliner tool, project team can simulate construction process by manually entering information about task or importing project planning software and linking building elements and schedules. In addition, planned sequences of construction activities can be simulated and timeliner also can automatically update the simulation if model or schedule changes. It has built-in scheduling application to manage tasks and there is a dialog to add, remove and refresh in order to deal with external data sources.

Realtime navigation of building is also possible through the virtual mockup with walkthrough and flythrough options. Creation of virtual mockup of construction systems can also increase the constructability of complex buildings.

Therefore, project team can plan construction operations effectively. Potential problems and clashes can be identified and as a result, construction cost can be decreased and productivity can be improved. Moreover, it provides better understanding of project and construction schedules due to visualization and communication. Locations of facilities on site can be evaluated during multiple phases of construction process. Site management decisions and material delivering can be facilitated due to integration of model with information about equipment locations and material staging areas so that it can be used for material planning and management because parameters can be added to elements to track their ordering and delivery status. With the integration of equipment, resources and material resources with BIM model, better schedules and cost estimation can be provided with 4D scheduling (autodesk.com).

4D BIM models change many of the practices of conventional scheduling. For example, entire construction site can be viewed. It is able to look inside and outside of the building and move around. Conflicts can be detected and solved at an early stage. However, conventional scheduling methods can not address the spatial aspect to construction activities and they can not directly link with model. Therefore, traditional bar charts can be more difficult to understand. However, 4D BIM models provide improved project schedules, identification and resolution of problems and access and manage project risks.

Chapter 4

SURVEY

4.1 Introduction

The information on the survey that was conducted among four architects who produced project drawings by using both AutoCAD and Autodesk Revit Architecture is given.

Furthermore another questionnaire on companies scale has been studied in this thesis. The detailed information on this questionnaire and how the Likert Scale was used is explained later in this thesis.

4.2 Interview of Architects

An interview was conducted with the four architects who prepared the specified project drawings. In order to assess the time efficiency of Autodesk Revit Architecture and AutoCAD, the applicability of project drawings, the duration of project drawings preparation and several industry related questions were prepared for the interview.

The interview included questions about their construction experience and their skill about using both AutoCAD and Autodesk Revit Architecture. In addition, respondents were asked to evaluate the advantages and disadvantages of both AutoCAD and Autodesk Revit Architecture and difficulties that were faced during the drawing stage as well.

Also the respondents were asked about their past experience in terms of the number of projects they did by using both of the softwares. The interview questions are found in Appendix A. Also, standard deviations of the needed time to draw specified project in both AutoCAD and Autodesk Revit Architecture were calculated by using equation 1:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n-1}} \quad \text{(Equation 1)}$$

Where n is the number of values, x_i is the each score and μ is the mean or average.

4.3 Questionnaire Survey among Construction Companies

A questionnaire was formed and conducted among twenty construction companies in North Cyprus. Questionnaires are any written instruments that present respondents with a series of questions or statements to which they are to react either by writing out their answers or selecting from among existing answers (Brown, 2001).

4.3.1 Design of Questionnaire

A questionnaire that include closed-ended and open-ended questions was designed according to the literature review. A questionnaire sample that was used in this thesis can be found in Appendix B.

The first part of questionnaire included closed-ended questions in order to get an idea about the area of expertise of respondents, experiences of respondents in terms of years and their duties in the company. Also, there was question about the types of projects that construction company builds such as residential building, industrial building, commercial building, complex building and others if any.

Another part was formed to measure the extension of duration factors and rework factors in construction projects and to get idea about average delay experienced and average rework amounts. Moreover, this questionnaire was formed to determine whether construction planning softwares and 3D modeling softwares are used in construction projects because project planning is fundamental to construction process and projects can not be controlled without a plan. It is crucial to develop a plan which is realistic and easy to follow to be able control and monitor projects.

In order to measure the extension of duration factors and rework factors in construction projects, possible factors of both the extension of duration and reworks were determined according to the research. Respondents were asked to rate the factors of the extension of duration of construction projects which include unexpected weather conditions, improperly configured site consultancy, inexperienced subcontractor, inexperienced workmanship, reworks, education and experience of the project staff, changing of client demands, coordination between personnel, changes due to design errors, late supply of material, incorrect calculation of material amounts, inadequacy of material, vehicle problems, complexity of work, slow decision making and disagreement between owner, contractor and subcontractor.

In addition, respondents were also asked to rate the factors of reworks which include inexperienced subcontractor, inexperienced workmanship, experience and education of project staff, changing client demands, changes due to design errors, communication between personnel, application error due to misunderstanding of project and complexity of work.

In this questionnaire the Likert Scale, the scale most commonly used to rate questions and to measure attitudes or opinions, was used. Responses were ranging from very important to not important with five answer options and each option with a dedicated score (Bowling 1997, Burns & Grove 1997). For example, “very important” corresponds to score of five, “important” to four, “medium” to three, “slightly important” to two and “not important” corresponds the score of one.

Questions were not complex for the sake of simplicity and survey was kept short to prevent respondents to feel bored so as to prevent unrepresentative answers.

There were also open ended questions about the extension of duration such as “what can be the solutions of these factors” and “what were the factors that caused timing problems” according to the experiences of respondents.

Open ended questions related with reworks were also asked. These questions were “what are the factors that affect rework apart from the factors that were given to rate” and “what type of reworks have you observed in your working life”.

4.3.2 Respondents

After the questionnaire was prepared, twenty construction companies in North Cyprus were asked to fill out the questionnaire. Questionnaires were delivered by hand to the companies and they were collected after completion. This may be a better way than mail surveys because there is such a possibility that questionnaire may not be returned via email.

4.3.3 Evaluation of Questionnaire

When questionnaires were collected from construction companies, they were evaluated. First, data were entered into Microsoft Excel and percentages of all factors were found. Then, all attributes were evaluated separately to obtain importance of each attitude by using the equation 2 (Ekanayake and Ofori, 2004). The mean importance rating of an attribute on such a scale is:

$$a= \frac{(1*n_1)+(2*n_2)+(3*n_3)+(4*n_4)+(5*n_5)}{n_1+n_2+n_3+n_4+n_5} \quad \text{(Equation 2)}$$

where a is the mean of importance rating of an attribute and $n_{1,}$ n_2, n_3, n_4, and n_5 are the number of subjects who rated the attributes as 1 (not important), 2 (slightly important), 3 (medium), 4 (important) and 5 (very important).

Then as attributes don't have the same importance degree, their weights were calculated by equation 3 which may vary from 0 to 1, where 0 corresponds not important and 1 is very important (Ekanayake and Ofori, 2004).

$$W_h = \frac{a_h}{\sum_{h=1}^{m} a_h} \quad \text{(Equation 3)}$$

Where h is the reference of attributes, m is the number of attributes, w_h is the weigth of attributes and a_h is the mean of importance. After calculation of weight of attributes, weight index of attributes (Wi_h) was calculated by using equation 4 (Ekanayake and Ofori, 2004).

$$Wi_h = \frac{w_h}{w_{max}} \quad \text{(Equation 4)}$$

Where w_{max} is the maximum weight of attributes which was calculated by using eq.3.

Chapter 5

RESULT AND DISCUSSIONS

5.1 Introduction

In this chapter, the result of the interview that was conducted among architects is discussed by explaining the answers of the interview to bring about the advantages and disadvantages of both AutoCAD and Autodesk Revit Architecture. Difficulties that architects observed during project drawings are discussed and the duration of preparation of project drawings by using both AutoCAD and Autodesk Revit Architecture is compared.

Results of architectural bill of quantity calculations that were manually calculated by four selected civil engineers are presented and the extraction of the architectural bill of quantities from the three dimensional intelligent model which was exported from Autodesk Revit Architecture to Autodesk Quantity Takeoff and which was generated in Autodesk Revit Architecture is explained.

Finally, results of a questionnaire that was conducted among twenty construction companies in North Cyprus are explained. The evaluations of the attributes, weight of attributes and the results of questionnaire on the factors of both reworks and the extension of duration of construction projects are discussed.

5.2 Results of Interview among Architects

Three architects who produced drawings by using both AutoCAD and Autodesk Revit Architecture have construction experiences not more than 5 years whereas the other participant is still an architecture student.

The needed time for preparing the specified project drawings by each architect was recorded. The duration comparison results show that all architects completed project drawings in less time when Autodesk Revit Architecture is used. The details are given in the table below.

Table 9. Time spent to draw project in AutoCAD and Autodesk Revit Architecture

Architects	**Time Spent in AutoCAD (minutes)**	**Time Spent in Autodesk Revit Architecture (minutes)**
1	496	119
2	515	145
3	722	250
4	625	180
Average	589.5	173.5
Standard Deviation	105.05	56.79
Standard Deviation σ +mean	694.6	230.3
Standard Deviation σ - mean	484.4	116.7

Also, past experiences of three architects and one architecture student in terms of how many projects they have prepared up to now in both AutoCAD and Autodesk Revit Architecture are shown in Table 10.

Table 10. Number of projects that architects have prepared up to now in both AutoCAD and Autodesk Revit Architecture

Architects	**Projects in AutoCAD**	**Projects of Autodesk Revit Architecture**
1	95	40
2	60	15
3	More than 50	42
4	65	25

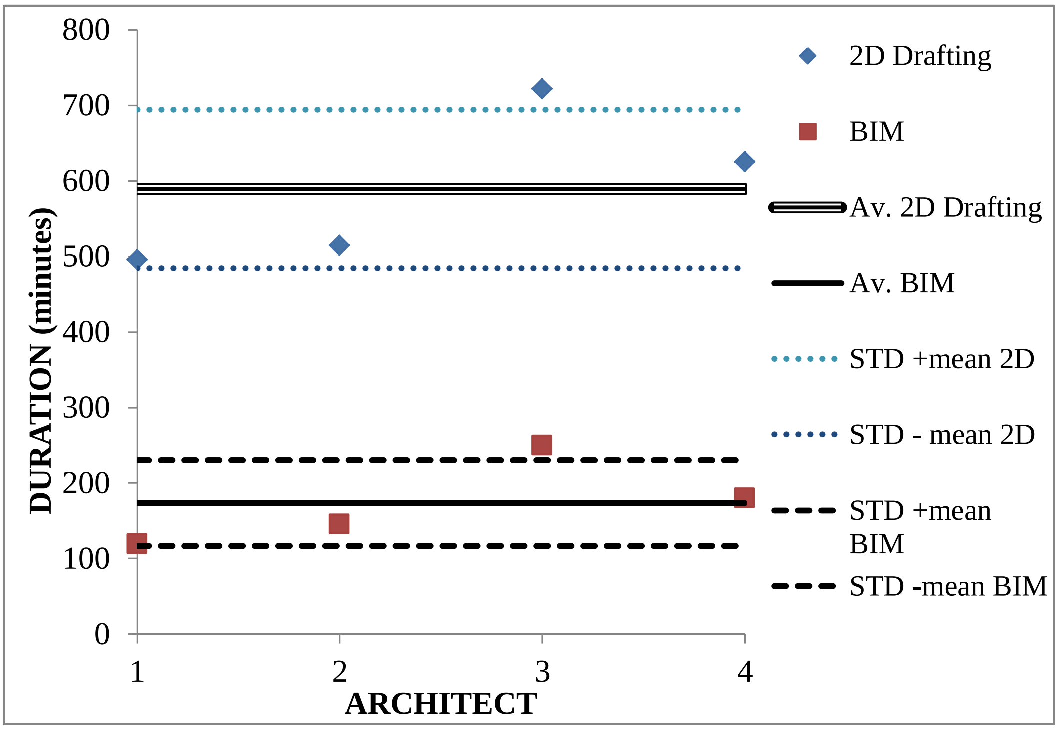

Figure 22. Comparison of case study project drawing durations for both methods

The figure 22 above shows the drawing duration differences between 2D drafting and BIM solutions. As the participants for this research have various experience differences, then the research gives a general idea among durations. When average results are compared, it can be seen that needed time for 2D drafting is 3.4 times more when compared with BIM solution.

Furthermore when standard deviations are analysed, the higher $\pm$ σ variations obtained from the 2D drafting method. This high variation in duration indicates that experience could decrease the duration with a high amount. In other words it can be said that, 2D drafting method is found to be more difficult to learn when compared with BIM solution. This is due to the $\pm$ σ variation of BIM is lot less than 2D drafting.

Moreover, as it be seen in Table 10, all of the participating architects have worked more on 2D drafting AutoCAD than the BIM Autodesk Revit Architecture. That means they have more experience in AutoCAD than Autodesk Revit Architecture. However, the average results show that architects spent 589.5 minutes in AutoCAD to prepare project drawings and 173.5 minutes in average was spent in Autodesk Revit Architecture. Therefore, results clearly show that overall duration to prepare project drawings in Autodesk Revit Architecture is 3.4 times shorter than the duration to prepare project drawings by AutoCAD, although the architects have more experience on AutoCAD.

According to the results that were obtained in this study, if it is assumed that architects in construction company prepare totally 100000 m^2 project drawings for residential buildings per year, there will be 703.89 hours savings per year if Autodesk Revit Architecture is used in terms of producing project drawings. Therefore, it can be concluded that Autodesk Revit Architecture provides advantages for economical purposes because number of architects that are needed to produce project drawings can be decreased so that money and time can be saved.

According to the interview among four architects, although AutoCAD is easy to use and can be used with keyboard to define commands, Autodesk Revit Architecture is faster and time can be greatly saved as can be seen from results. Generating drawings of sections, plans and views take time in AutoCAD because plans, side views, and sections are drawn separately line by line as shown in figures 23, 24, 25, 26, 27 and 28. In addition, if 3D model is required, another drawing should be generated because it can not automatically provide 3D view of the model. Also, if any change is done in any plan, the plan must be changed in all other views and sections manually. However, when elevations of building are defined and plans are generated in Autodesk Revit Architecture, objects can easily be copied to other plans and views, and sections can be automatically obtained. Therefore, it provides automatic views, plans, sections and 3D model generation faster that help to produce high quality drawings as it can be seen in figures 29, 30, 31, 32, 33, 34, 35, 36 and 37. If there is a problem related with the details in the project, it can be solved with this software due to automatic warning system of Autodesk Revit Architecture. In addition, since visualization is possible with the software, different and innovative ideas can be imagined while designing. Last but not least is that Autodesk Revit Architecture automatically updates other views and plans once any modification is done elsewhere.

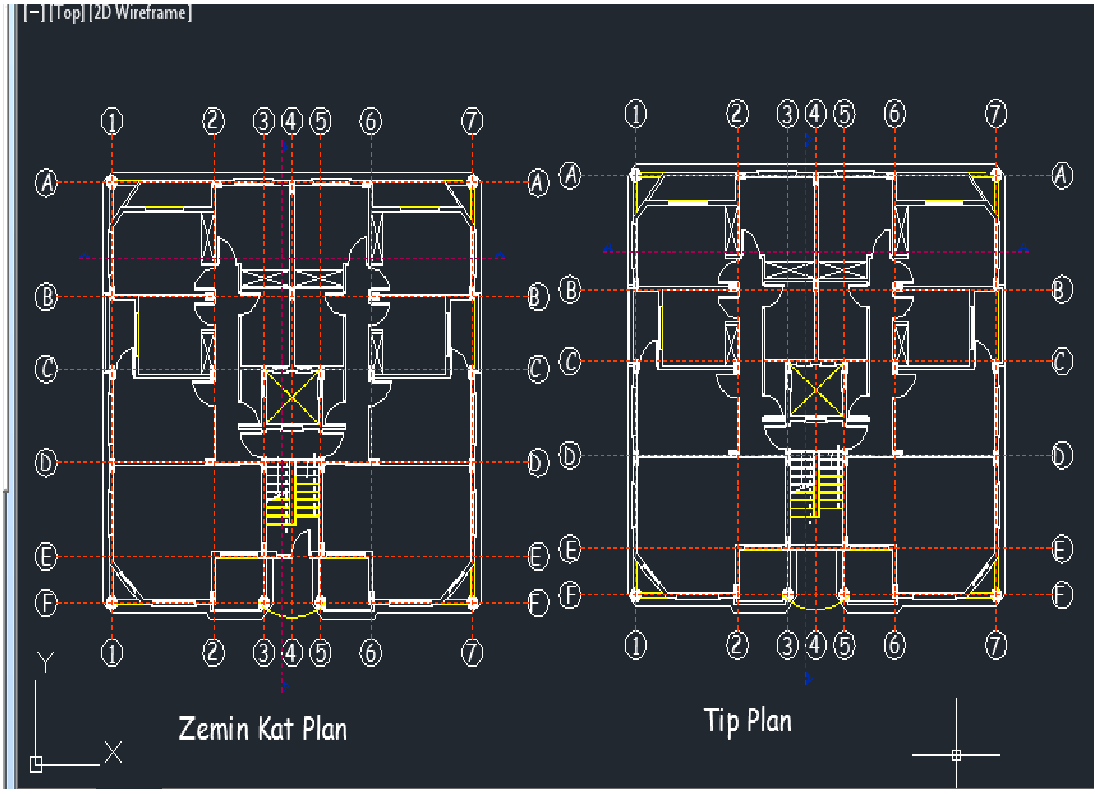

Figure 23. Ground floor plan and first /second floor plans of the apartment building in AutoCAD (2D drafting)

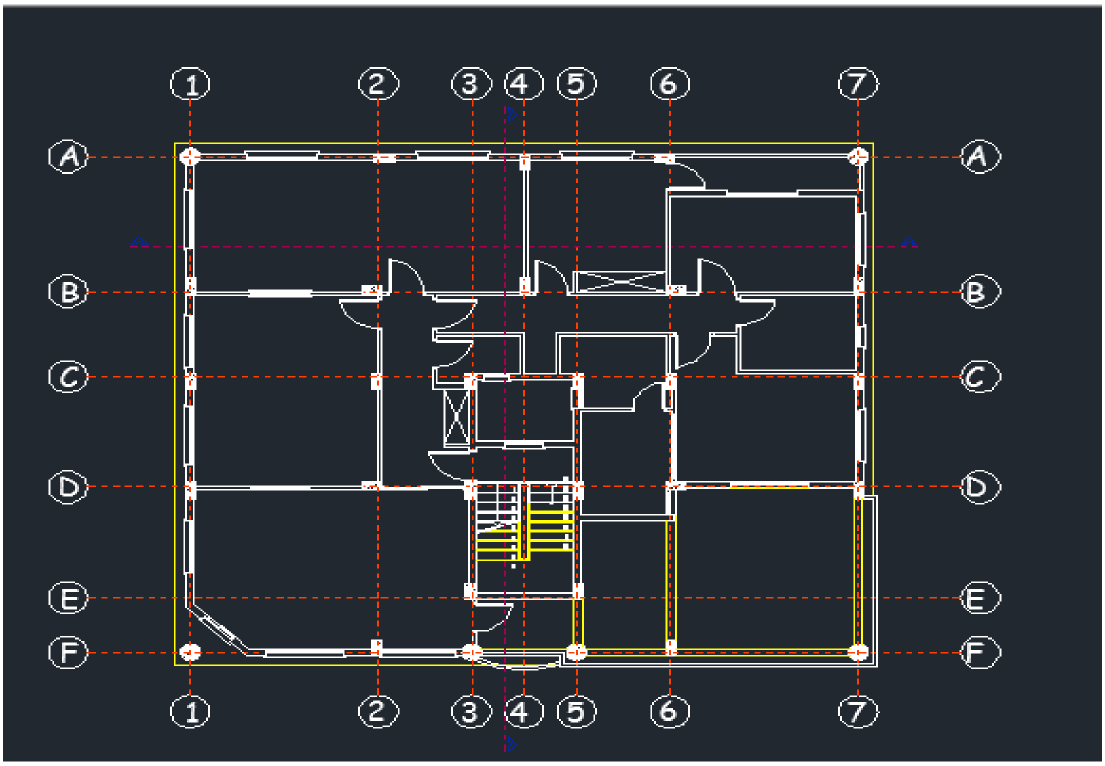

Figure 24. Third floor plan of apartment building in AutoCAD

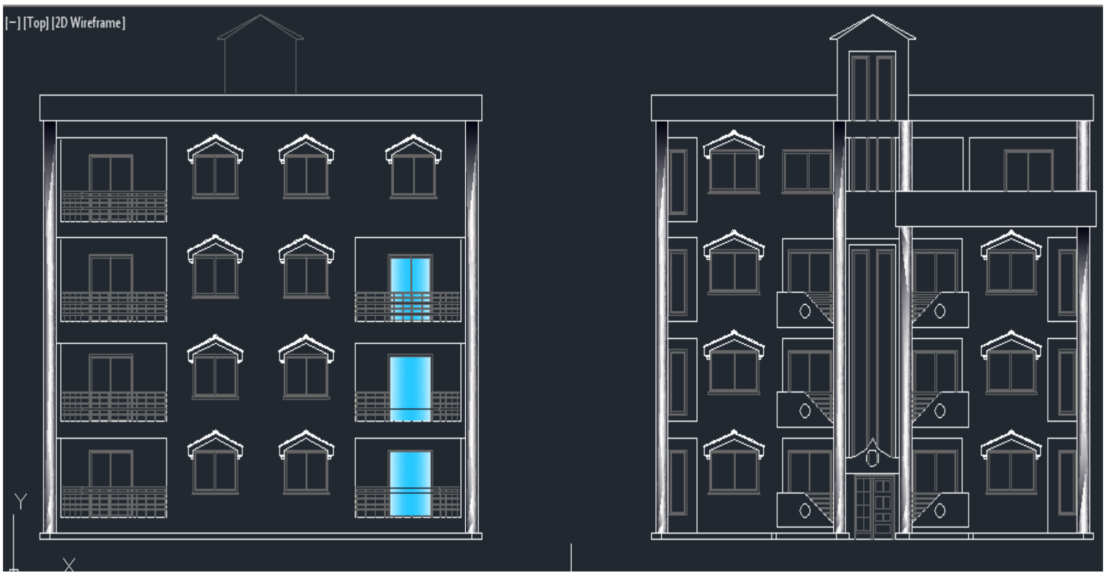

Figure 25. North and south views of the apartment building in AutoCAD

Figure 26. East and west side of the apartment building in AutoCAD

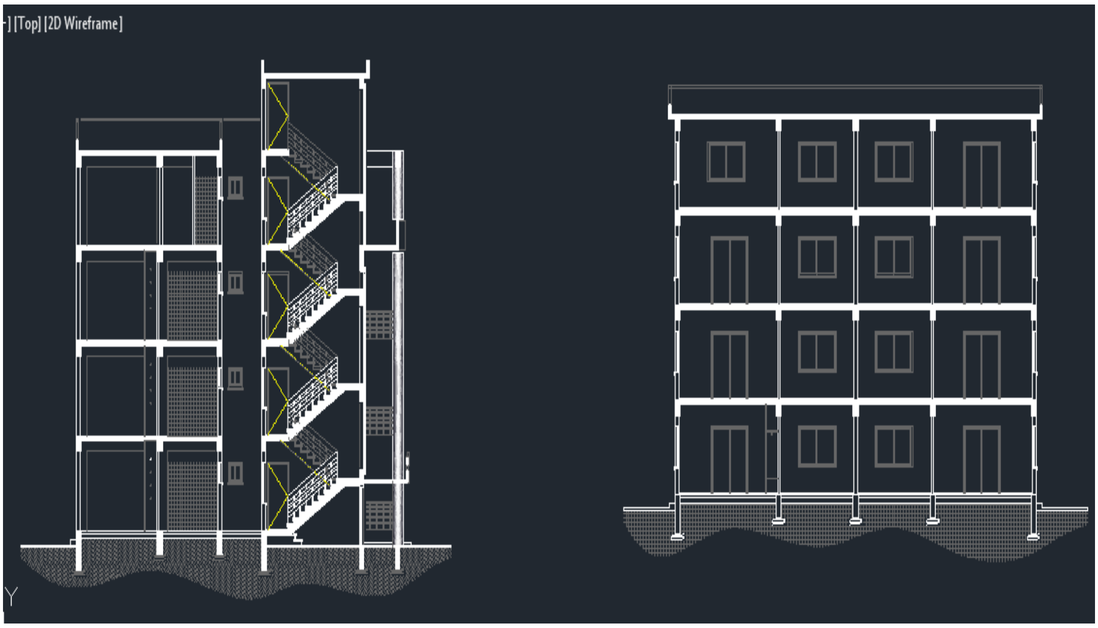

Figure 27. Sections of apartment building in AutoCAD

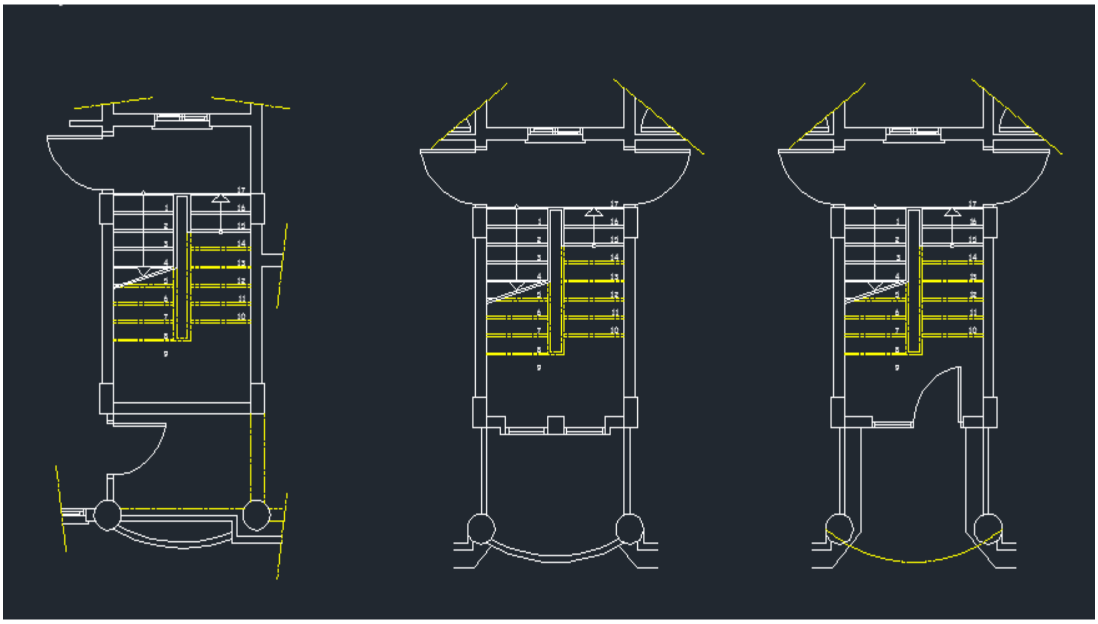

Figure 28. Staircase plans of apartment building in AutoCAD

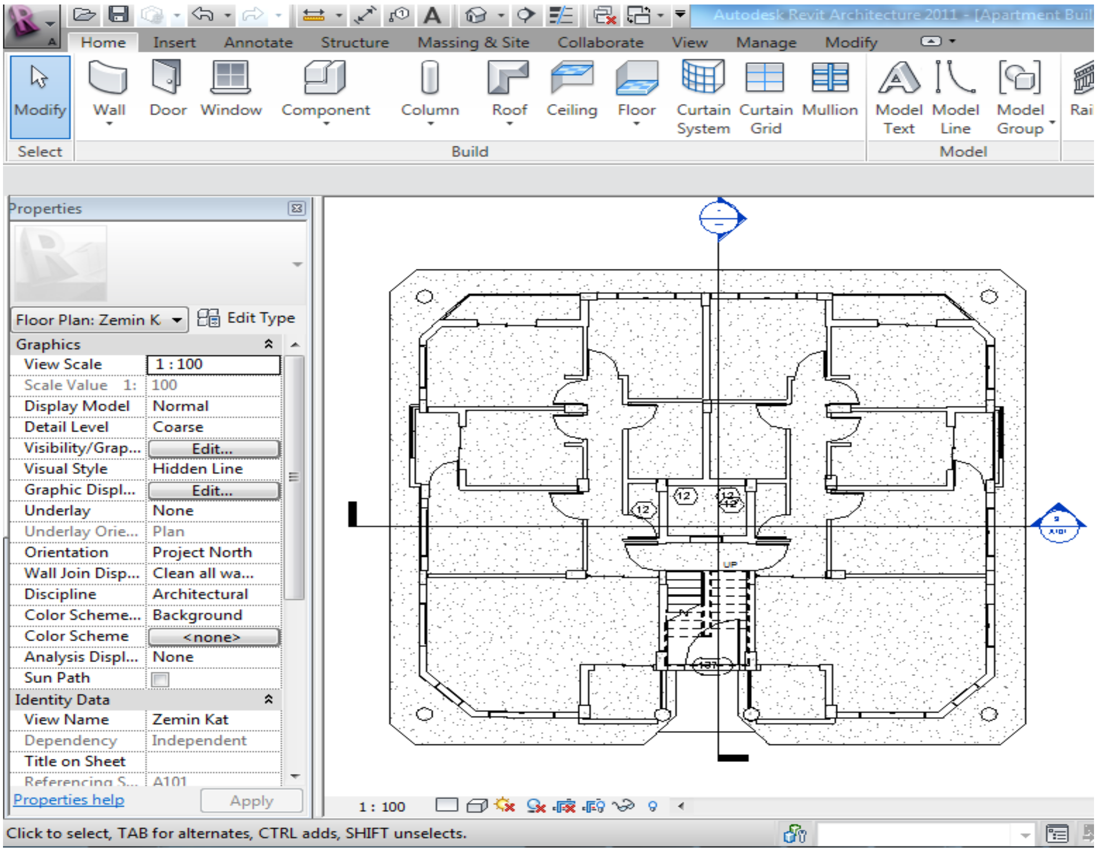

Figure 29. Ground floor plan of apartment building in Autodesk Revit Architecture

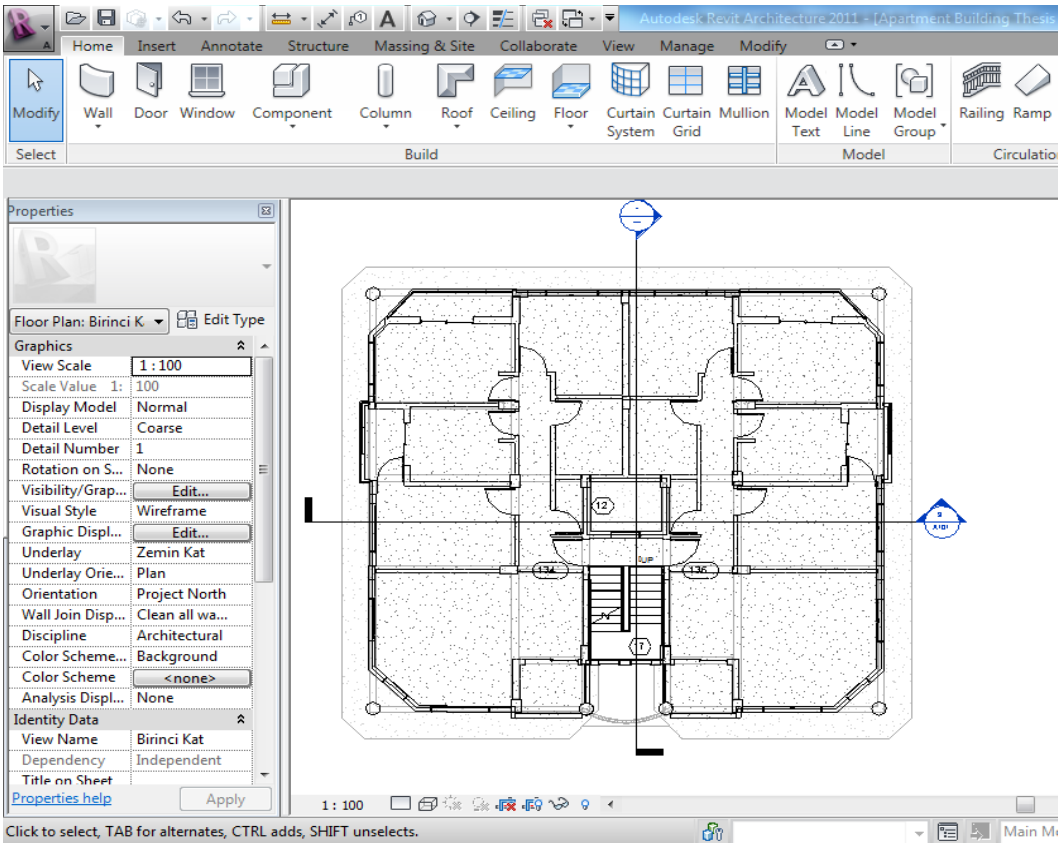

Figure 30. First and second floor in Autodesk Revit Architecture

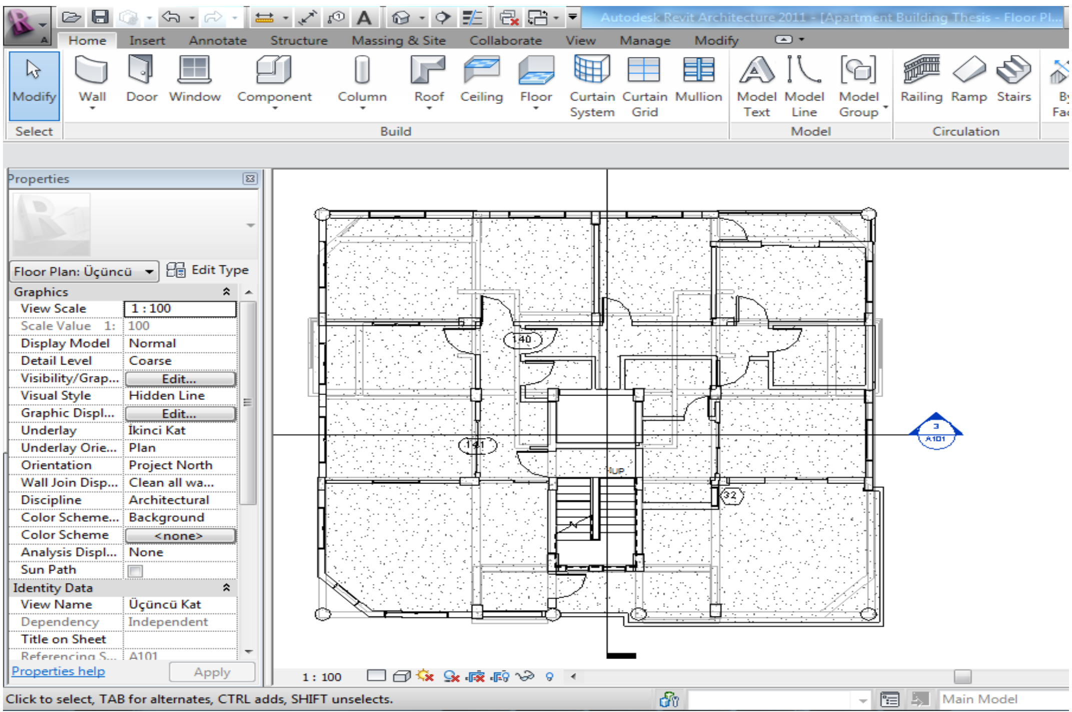

Figure 31. Third floor in Autodesk Revit Architecture

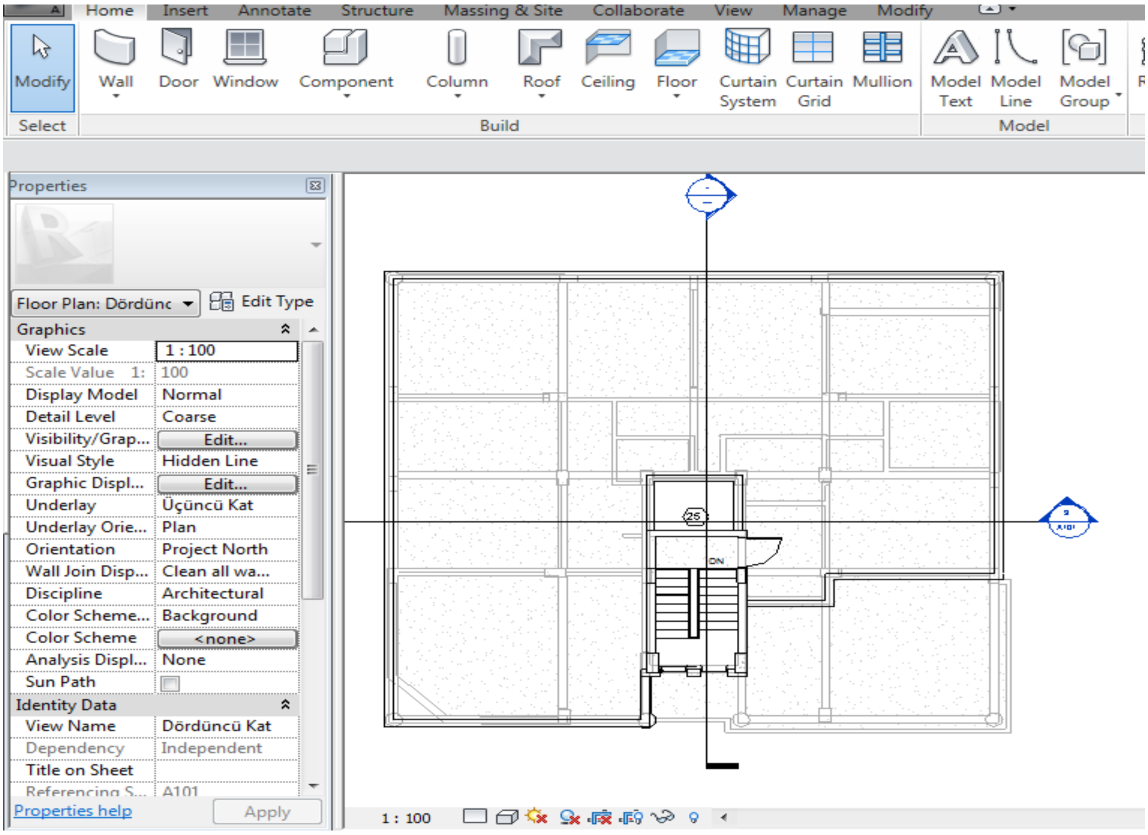

Figure 32. Penthouse plan of apartment building in Autodesk Revit Architecture

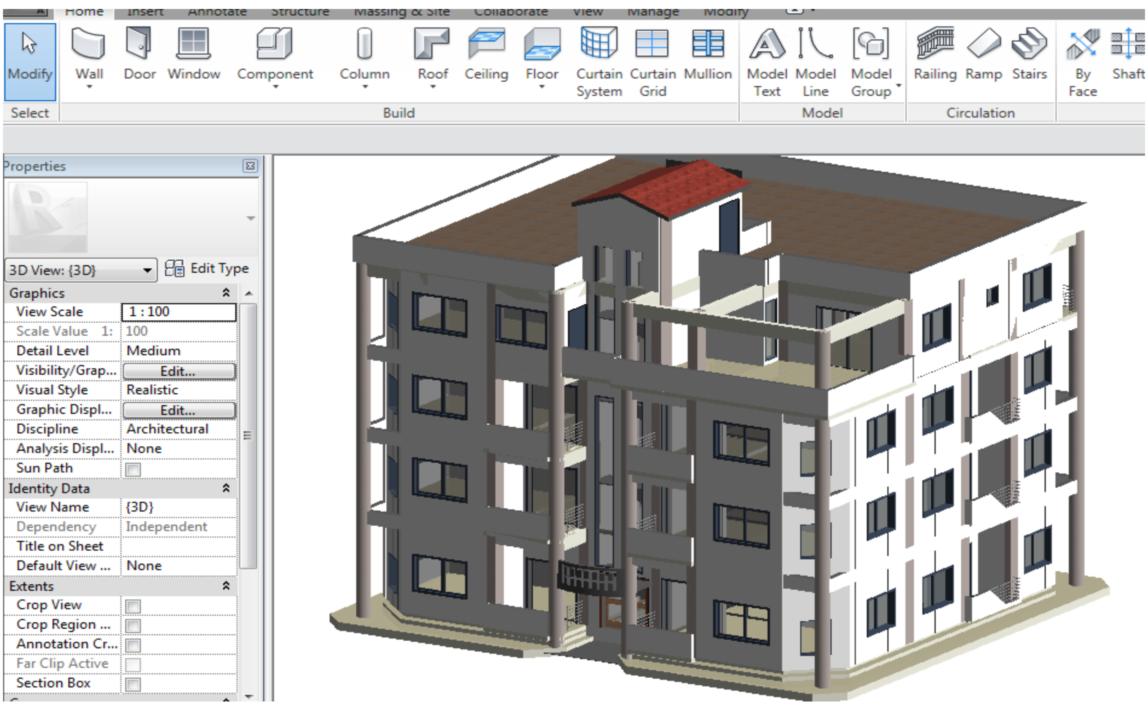

Figure 33. 3D View of the apartment building in Autodesk Revit Architecture

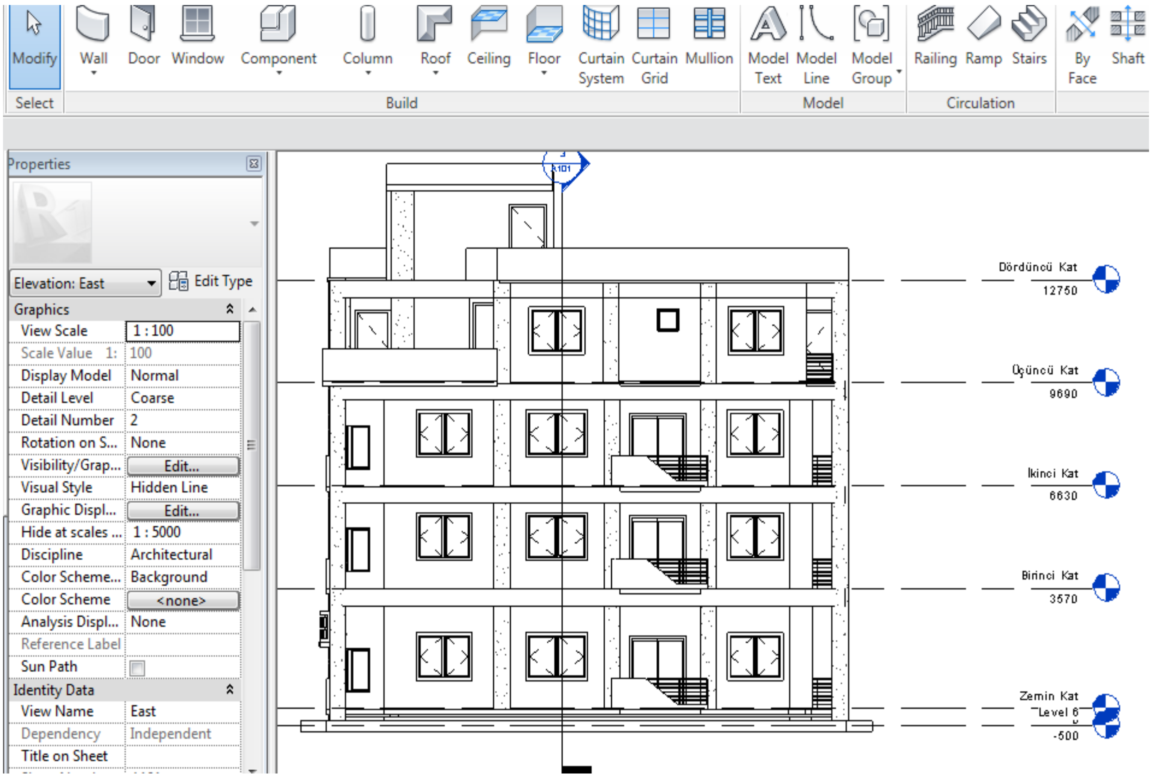

Figure 34. West side view of the apartment building

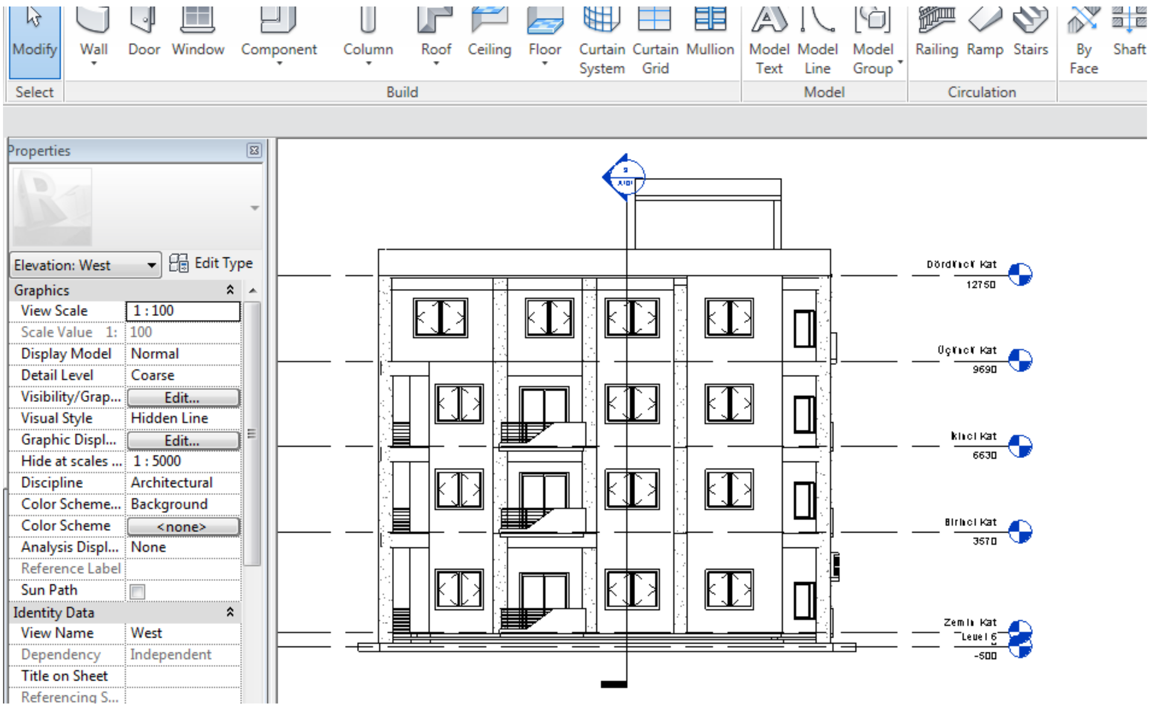

Figure 35. East side view of the apartment building

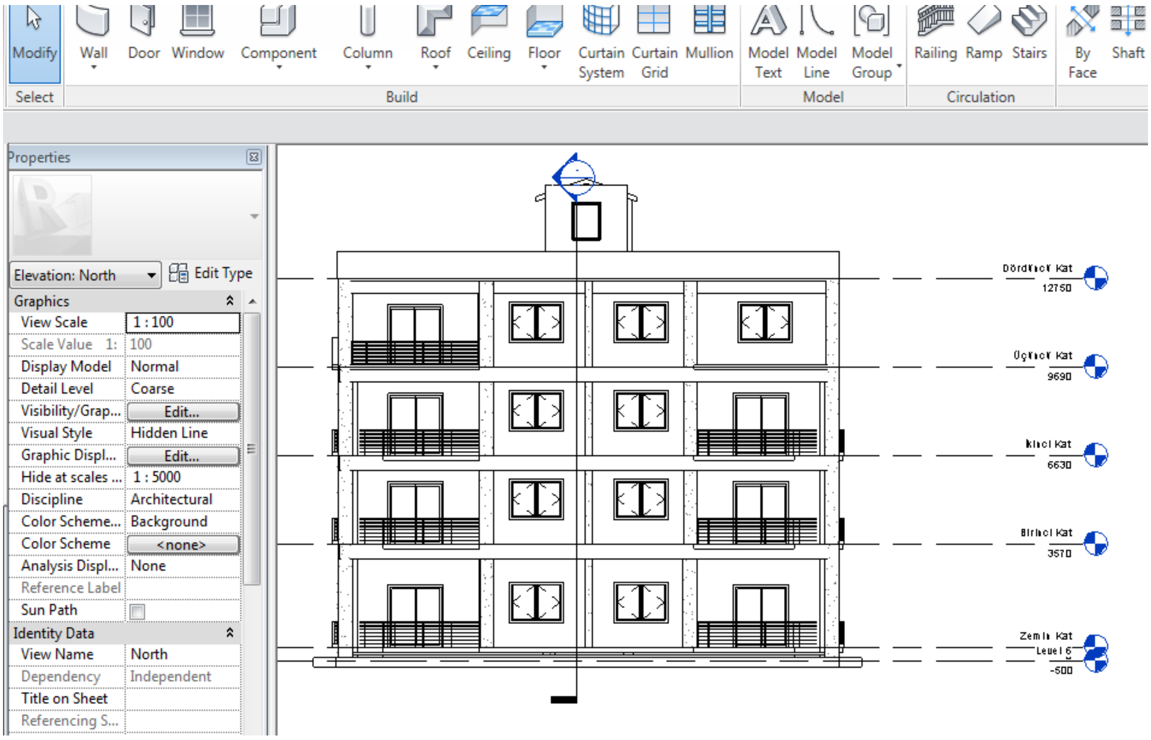

Figure 36. North side view of the apartment building

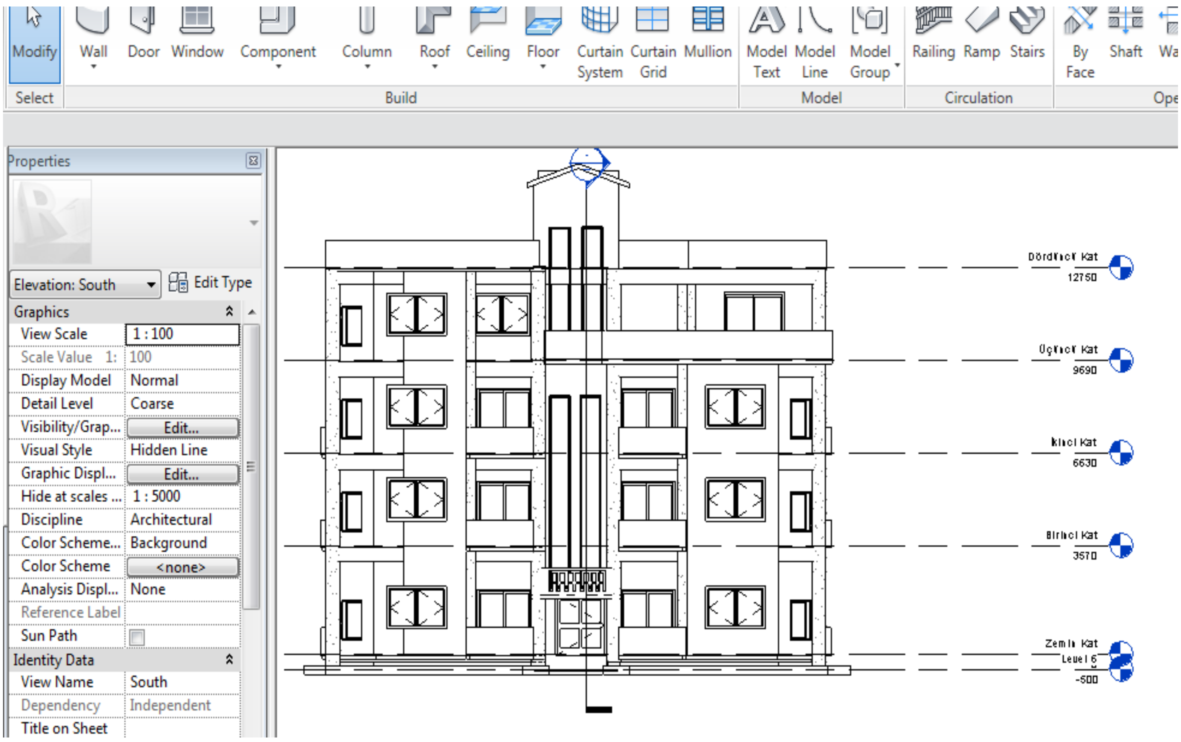

Figure 37. South side view of the apartment building

5.3 Quantity Takeoff

Quantity takeoff is a very time consuming process and it is an important part of estimation so results must be accurate to obtain good estimation and to win more bids when tenders are considered.

In this study, 985 m^2 apartment project case study is used and drawn by using AutoCAD. Then the architectural bill of quantities were calculated manually by selecting four experienced civil engineers. Then the architectural bill of quantities were extracted from Autodesk Revit Architecture. Also, Autodesk Revit Architecture model was used to export to Autodesk Quantity Takeoff to extract the architectural quantities automatically.

5.3.1 Manual Bill of Quantity Calculations

Manual calculations were carried out by selected four civil engineers to calculate the quantities of doors and windows, brickwork, plaster, painting and floor. Manual calculations of these quantities took long time because each dimension was measured on the hardcopies of 2D drawings manually. Because of that, there was a high possibility of doing mathematical error leading to mistakes in bill of quantity calculations. Table 11 summarizes the manual architectural bill of quantity calculations of apartment building project that was calculated by four the civil engineers.

Table 11. Summary of manually calculated architectural bill of quantities

Item	Description of Work	Unit	Quantity				Average
			Civil Eng. (1)	Civil Eng. (2)	Civil Eng. (3)	Civil Eng. (4)	
A	Brickworks	m^2	1366.1	1356.3	1346.5	1442	1377.7
B	Plastering (1coat)	m^2	3625	3406.7	3696.3	3399.7	3531.9
C	Painting	m^2	3625	3406.7	3696.3	3399.7	3531.9
D	Floor Tiles	m^2	926.9	909.1	940.2	979.5	938.9

As it can be seen from the table 11, there are differences between quantities. In the case of brickwork calculations out of four quantities, the lowest amount among calculated quantities by four civil engineers was 1346.5 m^2 and highest quantity was 1442 m^2, it means there is 95.5 m^2 difference between quantities. If plastering or painting quantities are compared, the lowest quantity was 3399.7 m^2 and highest quantity among four civil engineers was 3696.3 m^2 and there is 296.6 m^2 difference between the quantities. Also, if floor areas are compared, it can be seen that there is 70.4 m^2 area difference between highest and lowest quantities. Therefore, it can be concluded that manual bill of quantity calculations can lead to differences between quantities.

5.3.2 Quantity Takeoff Process by Using Autodesk Revit Architecture and Autodesk Quantity Takeoff

When apartment building was drawn in Autodesk Revit Architecture, quantities of the all building elements in the model was generated automatically with the material takeoff feature of Autodesk Revit Architecture in 1 minutes. Then, Autodesk Quantity Takeoff which is one of the softwares that is used to extract quantities from a model was also used to extract quantities by exporting model into Autodesk Quantity Takeoff. Autodesk Quantity Takeoff generated bill of quantities in 1 minute due to its practicability. Unit type of quantities could also be changed quickly according to preferences. Moreover, when doors and windows were selected for take off, all windows and doors in whole building were given in the list with the sizes and quantities. Normally, it was difficult and time consuming to count all doors and windows from the architectural plan one by one manually but Autodesk Quantity Takeoff gives the list of doors and windows quickly with the numbers and dimensions.

Table 12. Summary of architectural bill of quantities generated in both Autodesk Revit Architecture and Autodesk Quantity Takeoff and manual calculations

Item	**Description of Work**	**Unit**	**Quantity (Autodesk Revit Architecture)**	**Quantity (Autodesk Quantity Takeoff)**	**Average Quantity (Manual)**
A	Brickworks	m^2	1688	1696	1377.7
B	Plastering (1coat)	m^2	3554	-	3531.9
C	Painting	m^2	3554	-	3531.9
D	Floor Tiles	m^2	1005	1004.3	938.9

Once manual calculations and extracted quantities are compared, the average amount of brick that was calculated manually by civil engineers was found out to be 1377.7 m^2. On the other hand, the area of brick quantity was extracted as 1688 m^2 in Autodesk Revit Architecture and 1696 m^2 in Autodesk Quantity Takeoff. There is 310.3 m^2 difference between the quantities that were obtained by using Autodesk Revit Architecture and manual calculations. This difference is obtained as the manual calculations consider beam depths and excludes from the area. However the Autodesk Quantity Takeoff and Autodesk Revit Architecture did not consider the beam depths and the found total wall area is more than the manual calculations. If plaster or painting quantities are considered, the manually calculated quantity was found as 3531.9 m^2 and quantity extracted from Autodesk Revit Architecture was

3554 m^2. Therefore, when the accuracy of calculations obtained from Autodesk Revit Architecture was compared with the accuracy of manual calculations of four civil engineers, the accuracy of manual calculations was found to be 99.37% whereas the accuracy of the automatic takeoff was 100%. In the case of floor area, total floor area of building was manually calculated as 938,9 m^2 in average and when floor area was extracted from the Autodesk Quantity Takeoff, it was 1004.3 m^2 and it was extracted as 1005 m^2 in Autodesk Revit Architecture so that the accuracy of manually calculated floor quantity by four civil engineers was found to be 93.42% whereas the accuracy of automatic takeoff was 100%.

As it was mentioned, since there were small differences between some of the quantities which were calculated both manually by four civil engineers and extracted automatically from Autodesk Quantity Takeoff and Autodesk Revit Architecture, it can be concluded that there is possibility of doing mathematical errors during manual bill of quantity calculations whereas there is no possibility of doing mathematical errors in quantities by using software because it directly gives the quantity. Therefore, it is believed that accuracy of the results are high in BIM as the mathematical errors emerging from manual calculations do not occur in the software. Thus the estimator productivity and accuracy increases. As Baalousha (2011) defines, “When the accuracy of calculations of the model (DANUP) was compared with the accuracy of manual unit cost calculations of ten estimators, out of 100 unit cost calculations, the number of correctly calculated unit costs by ten estimators on average was found to be 92, whereas the accuracy of the model was evaluated as 100%.”

In addition to the accuracy of results, the needed time to calculate the bill of quantities manually is longer than the automatic quantity takeoff. Table 13 gives details about the duration that was spent to calculate brick quantity manually.

Table 13. Duration of bill of quantity calculations obtained manually and automatically

Item	**Description of Work**	**Duration (Min)**		
		Average of Manual Calculations	**Autodesk Revit Architecture**	**Autodesk Quantity Takeoff**
A	Brickwork	64.75		
B&C	Plaster/Painting	85.75		
D	Floor Tiles	27.75		
Total Duration (Min)		178.25	Less than 1	Less than1

As it can be seen in Table 13, the average time that was spent to calculate brickwork, plaster/painting and floor tiles was 178.25 minutes in total and the automatic takeoff just needed less than 1 minutes to extract the quantities automatically which was 178.25 times longer than the duration of automatic quantity takeoff. That means Autodesk Quantity Takeoff and Autodesk Revit Architecture are almost 178.25 times more time-efficient than manual calculations and it can be concluded that BIM provides advantages while obtaining these quantities since the process is automatic which helps to decrease the amount of time consumed.

Therefore if it is assumed that, quantity surveyers in a construction company prepare architectural bill of quantity calculations manually for residential buildings which have 100000 m^2 area in total per year, it will take 301.6 hours to prepare architectural bill of quantity calculations manually according to the case study that was carried out in this thesis. Also, the needed time to calculate bill of quantities of construction projects also depends on the complexity of the project. However, if Autodesk Revit Architecture is used to extract architectural quantity, whatever the size and compexity of project, bill of quantities can be extracted in less than 1 minute automatically. Therefore, it can be concluded that time can be greatly saved with BIM and the possibility of doing mathematical errors in bill of quantity calculations can be minimized due to its automatic takeoff feature.

5.4 Results of Survey among Construction Companies

Building Information Modeling is not widely used in North Cyprus. So the effect of using BIM in construction projects was tried to be measured by evaluating the factors that affect the extension of duration of the contruction projects and reworks by conducting a questionnaire among twenty construction companies. Details about the type of twenty construction companies that participated questionnaire are given in Table 14 and most of the companies have the type of bid, design and built.

Table 14. Type of the companies that participated questionnaire

Type of Company		
Design- Builder	**Bid-Design-Built**	**Contracting Firm**
30%	50%	20%

In addition, the details about the respondents’ area of expertise, their duties in construction companies and their experiences in terms of years are given in Table 15, Table 16 and Table 17. Civil engineers from the construction companies were the largest group of respondents. In addition, the details about the type of projects that twenty construction companies built are given in Table18.

Table 15. Respondents’ area of expertise

Area of Expertise			
Director	**Contractor**	**Civil Engineer**	**Building Technician**
15%	5%	75%	5%

Table 16. Respondents’ duty in construction companies

Duty in Construction Company					
Director	**Contractor**	**Designer**	**Site Engineer**	**Quantity surveyor**	**Designer and Controller**
15%	5%	10%	40%	15%	15%

Table 17. Respondents’ experience in terms of years

Experience in Years					
0-5	**6-11**	**12-20**	**21-25**	**26-30**	**More than 30**
50%	30%	15%	0%	5%	0%

Table 18. Type of projects that construction companies built

Type of Work	%
Residential, Industrial, Commercial and Complex Buildings	5
Residential Buildings	55
Residential, Industrial and Commercial Buildings	10
Commercial Buildings	15
Complex Buildings	5
Residential and Industrial Buildings	10

Application of Microsoft Project (Construction Planning Software) is of great importance in construction projects especially when the duration of all activities is needed. Contruction companies were asked to evaluate how often Microsoft Project is used in construction projects in North Cyprus and the results of the questionnaire show that, 95% of the companies use Microsoft Project in their projects. The details about the use of Microsoft Project are given in Figure 38.

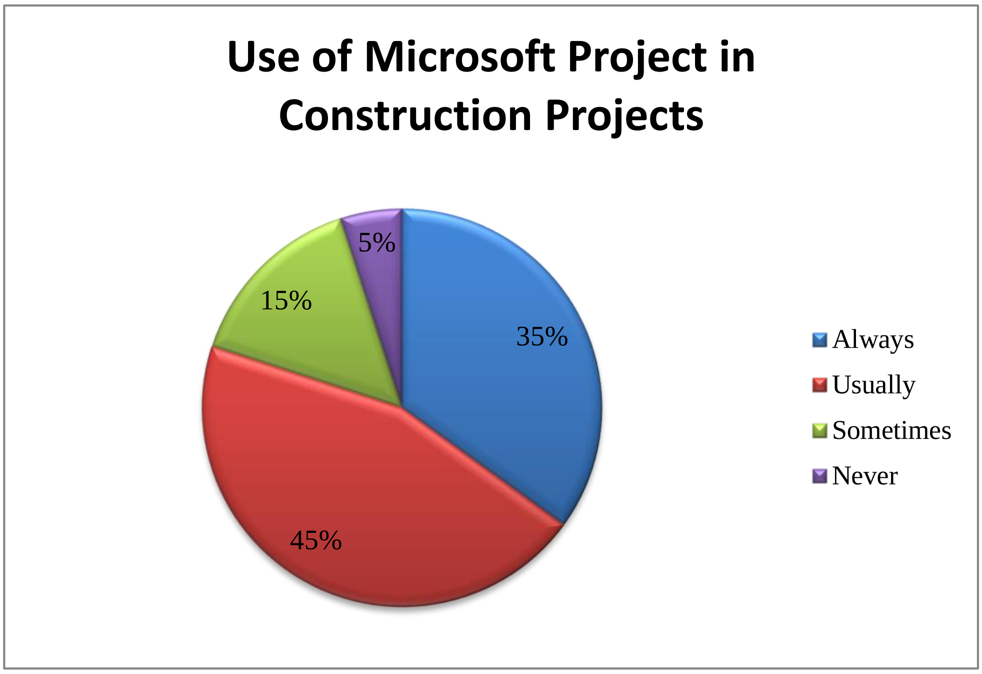

Figure 38. Application of Microsoft Project in construction projects

Also, since several questions were asked to evaluate the extension of duration factors, the question about average delay amounts of projects was also asked to the construction companies. The most of the companies (30% of the 20 construction companies) answered that the generally delay in projects is approximately between 26% and 30% in North Cyprus and average delay amount is not more than 55%. Figure 39 gives detailed information on the results of average delay amount in construction projects among twenty construction companies.

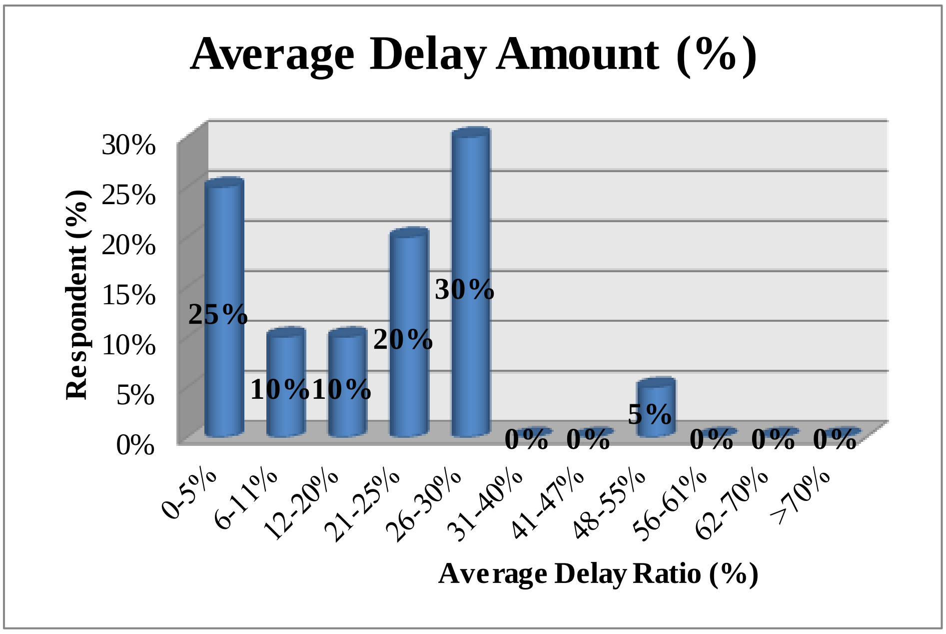

Figure 39. Average delay amount of construction projects

It is believed that the 3D BIM models are very useful for the interpretation and visualisation of the projects, as mentioned earlier. Since BIM is not used in North Cyprus, some of the companies use 3D models (not BIM models) of construction projects just for marketing purposes and to affect customers. From the results of the questionnaire, 81% of the construction companies use 3D models in North Cyprus and 19% of the companies do not use it. The details about how often 3D models are used in construction projects are given in figure 40.

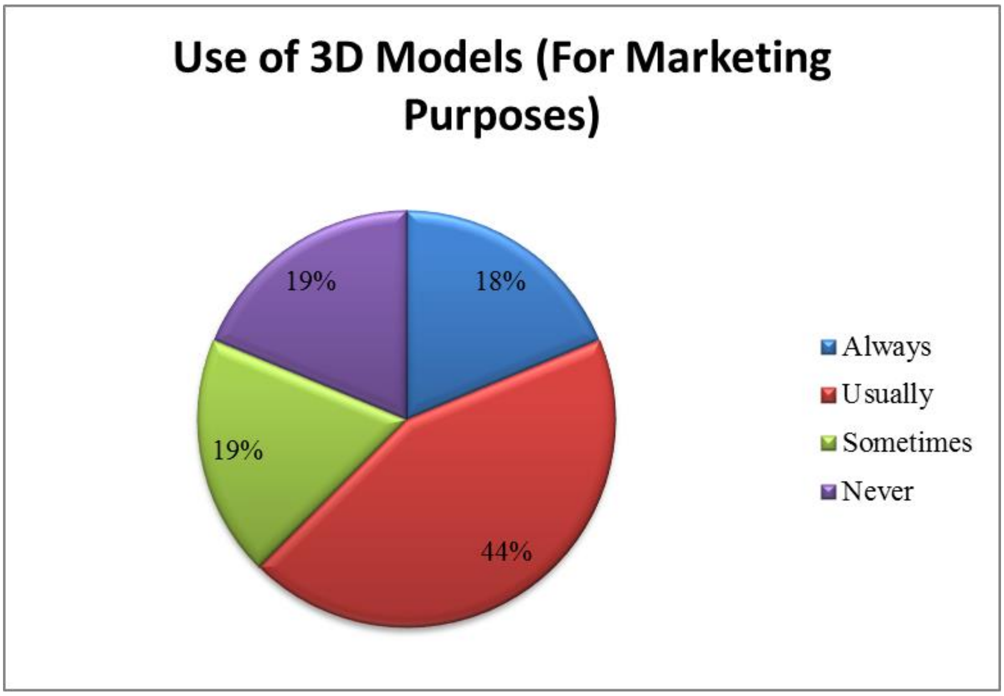

Figure 40. Use of three dimensional models in construction projects

On the other hand, besides the measuring of rework factors in construction projects, average rework amount was measured among twenty construction companies in North Cyprus. According to the questionnaire results, the most of the respondents (30% of twenty construction companies in North Cyprus) responded that the average amount of reworks that occur during construction is between 31% and 40 and average rework amounts are not more than 70%. This percentage is of significance and should not be omitted since once reworks arise during construction, extension of duration and an increase in the cost of the project occurs. Figure 41 summarizes the responses of average rework amount in construction projects.

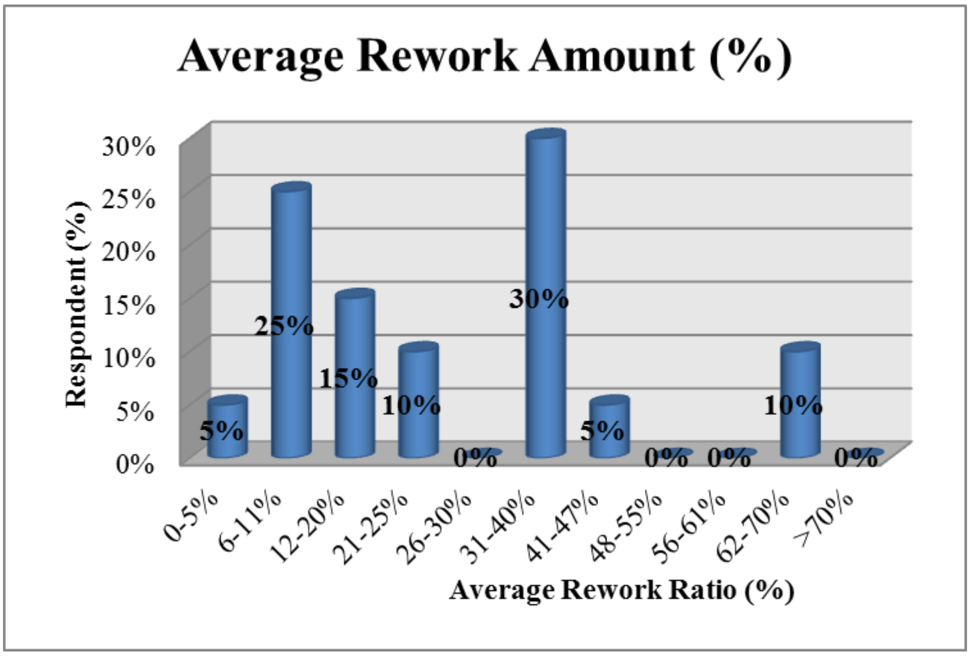

Figure 41. Average rework amount that was obtained in questionnaire

5.4.1 Factors Affecting the Extension of Duration of Construction Projects

There are many factors that have negative effects on on-time completion of project such as unexpected weather conditions, inexperienced subcontractor and workmanship, reworks, design changes, education and experience of project staff, changing demands of clients, coordination between personnel, improperly configured site consultancy, design errors, incorrect calculation of material amounts, inadequate of material, late supply of material, vehicle problems, disagreements between owner, contractor or subcontractor, complexity of work and slow decision making. These factors may arise at design stage or they may arise when construction starts on field and as a result, they may cause extension of construction durations. Therefore, twenty construction companies in North Cyprus were asked to evaluate the effect of these factors on the extension of duration and which factors can be solved with Building Information Modeling were analyzed. Result data were entered into

Microsoft Excel and result data that summarizes data obtained from questionnaire can be seen in Table 19.

Table 19. Number of attributes who rated the extension of duration factors from 1 to 5

Criteria and Attributes	#5 Very Important	#4 Important	#3 Medium	#2 Slightly Important	#1 Not Important
Unexpected weather conditions	9	6	4	1	0
Improperly configured site consultancy	8	7	4	1	0
In experienced subcontractor	10	7	1	2	0
Inexperienced workmanship	11	5	2	2	0
Reworks	11	7	1	1	0
Education and experience of project staff	7	10	3	0	0
Clients' changing demands	16	4	0	0	0
Coordination between personnel	8	8	4	0	0
Changes due to design errors	8	7	4	0	1
Late supply of material	8	10	2	0	0
Incorrect calculation of material amounts	7	6	4	2	1
Diminish of material	3	7	9	1	0
Vehicle problems	2	7	6	3	2
Disagreement between owner, contractor and subcontractor	8	8	2	1	1
Complexity of	3	3	9	5	0

work					
Slow decision making	7	9	2	2	0

After number of attributes was entered into Microsoft Excel, the mean of importance (a_h) for all factors were calculated by using equation 1 which was provided at methodolgy part and attributes were distinguished by calculating weights (w_h) by using equation 2 since attributes do not have the same degree of importance. Then weight of attributes was standardized by calculating weight index of attributes (Wi_h) by the equation 3 which may range from 0 to 1 where 0 represents not important and 1 represents very important (Ekanayake and Ofori, 2004) as in table 20.

Table 20. Mean of importance (a_h), weight (w_h) and weight index of attributes (Wi_h)

Criteria and Attributes	**Mean (a_h) (Eq.1)**	**Weight (w_h) (Eq.2)**	**Weight Index (Wi_h) (Eq.3)**
Unexpected weather conditions	4.15	0.064	0.868
Improperly configured site consultancy	4.1	0.063	0.858
In experienced subcontractor	4.25	0.066	0.889
Inexperienced workmanship	4.25	0.066	0.889
Reworks	4.4	0.068	0.920
Education and experience of project staff	4.2	0.065	0.879
Clients' changing demands	4.8	0.074	1.00
Coordination between personnel	4.2	0.065	0.879
Changes due to design errors	4.05	0.063	0.847
Late supply of material	4.3	0.067	0.900
Incorrect calculation of material amounts	3.8	0.059	0.795
Diminish of material	3.6	0.056	0.753
Vehicle problems	3.2	0.050	0.669
Disagreement between owner, contractor and subcontractor	4.05	0.063	0.847
Complexity of work	3.2	0.050	0.669
Slow decision making	4.05	0.063	0.847

#1, not important; 2, slightly important; 3, medium; 4, important; 5, very important.

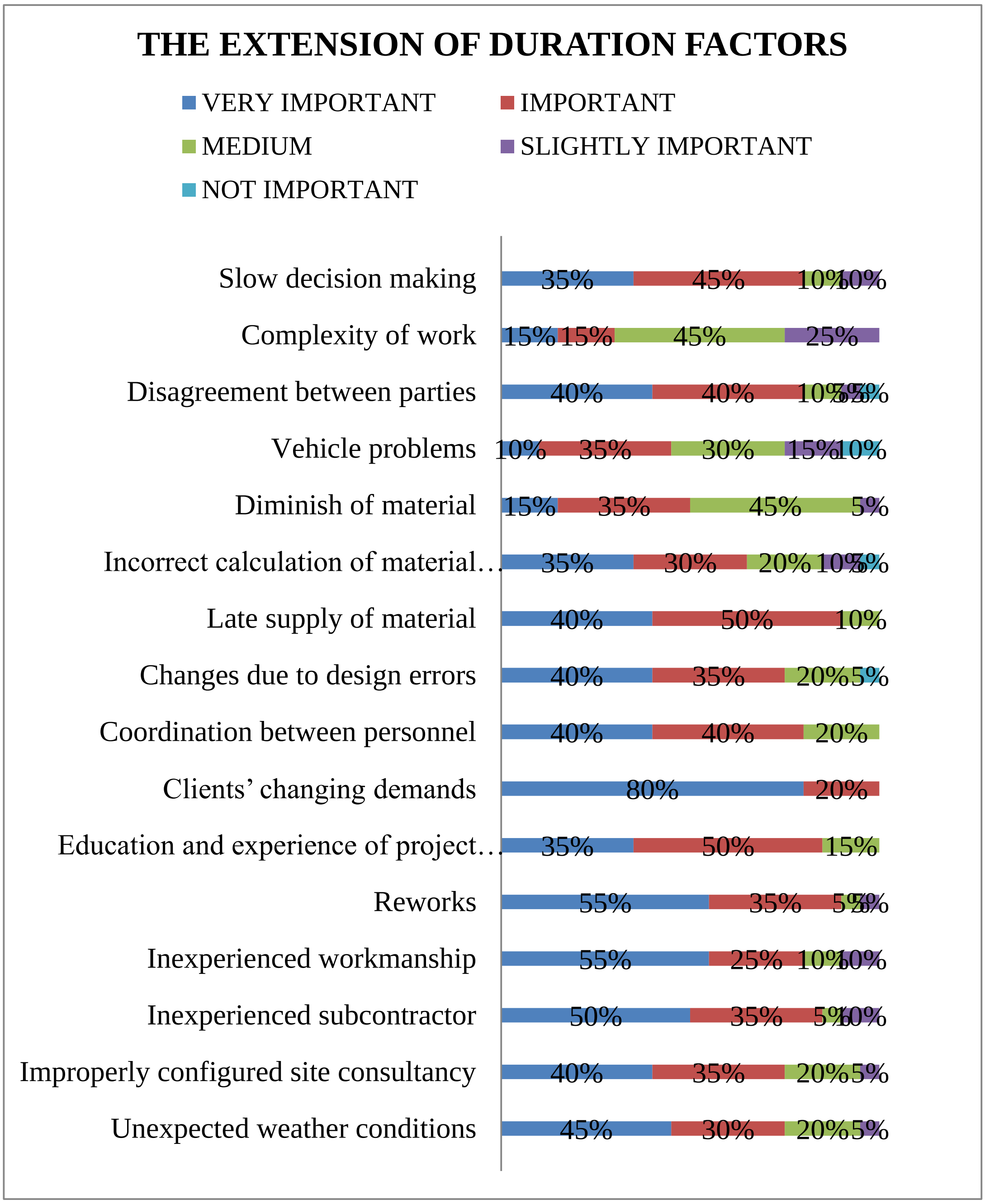

Figure 42. Calculated percentages of the extension of duration factors according to questionnaire results

Figure 42 shows the calculated percentages of all factors among twenty construction companies in the order of from very important to not important and figure 43 shows the bar chart of mean of importance of attributes out of 5 which is very important.

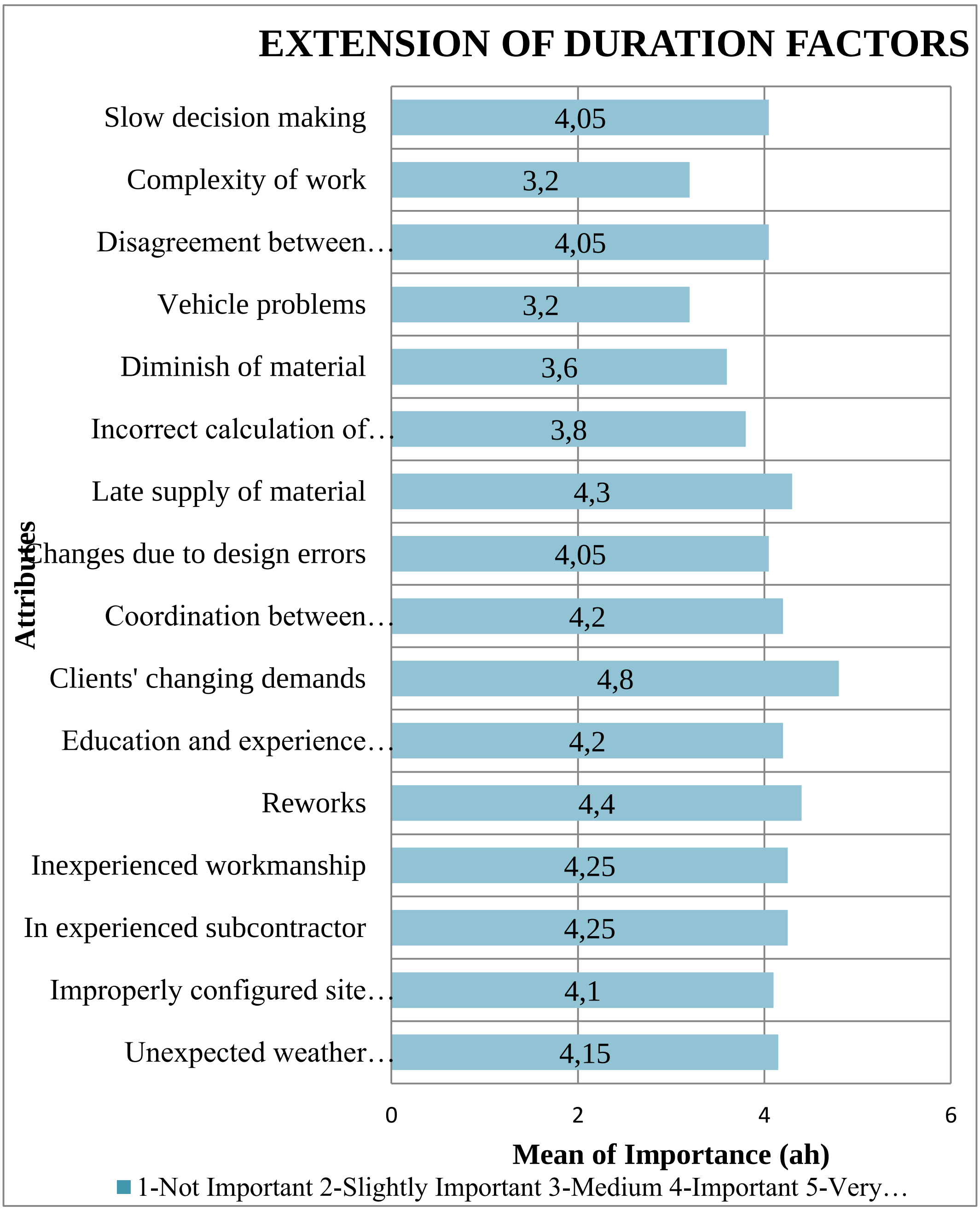

Figure 43. Bar chart of the mean of importance (a_h) of the extension of duration factors

According to the questionnaire results, the most important reason of the extension of duration of construction projects is the changing demands of clients from participants' point of view because 80% of construction companies answered that it is very important and it also has the mean importance (a_h) of 4.8 out of 5 where 5 represents very important as it is shown in figure 43. Therefore, it can be concluded that the use of Building Information Modeling approach may be a valid solution for this problem. With the help of BIM technology, continuously changing demands of clients are expected to be minimized. Clients usually define their demands for project at the briefing stage and designers try to satisfy clients by designing project that meets the demands of clients. However, when construction starts and clients see the project in real life, they sometimes happen to change their demands and decisions and in turn this leads to change in design with the traditional methods as can be seen from the results. This may be because clients may not be technical people and they may not understand project from traditional methods (two dimensional paper based design). Therefore, if BIM technology that includes intelligent object oriented design is used, 3D visualization may enable clients to see whole aspect in detail and it helps to imagine what will be the end product (Azharet, 2010).

After the clients changing demands, reworks are another important factor with the mean of importance (a_h) of 4.4 out of 5 that affect the extension of duration of construction projects as understood from the survey and 55% of the 20 construction companies answered that it is very important. In North Cyprus, traditional methods (2D paper based drawings) are used to manage projects and when project starts in field, reworks due to several reasons and conflicts between different activities may arise and it may cause time and cost overruns (Love, 2002a). Thus BIM is expected to be good alternative to solve such problems or in order to avoid extensive reworks, a contract should be agreed on, before the start of the construction, including construction methods, duration of activities and definition for the type of materials that are to be used and there should be private decisions about changes in contract as explained in open-ended questions part of the questionnaire. Also, electrical, mechanical and structural departments should work together to prevent any delays, problems and errors that may occur in the field and this can be achieved BIM technology that provides a platform that all project parties are able to work on the same model and are able to solve these problems before construction starts on field. Project parties can use 3D models to detect conflicts visually and solving them to decrease the design errors (Hartmann, Gao, and Fischer, 2008).

In addition to the attributes mentioned above according to the mean of importance levels, late supply of material has the mean of importance value of 4.3, and inexperienced subcontractor and inexperienced workmanship have the same mean of importance of 4.25 out of 5 on the extension of duration. Therefore, some of materials or equipments are needed to be ordered earlier to prevent late supply. Otherwise, the plan and other works that are linked to each other can not be started and finished on time that causes delays in construction projects. On the other hand, more experienced subcontractors and workers are expected to contribute on time completion of construction projects. One should not completely fall for inexperienced subcontractor and inexperienced workers for the low price they offer. Additionally, existence of qualified and motivated workers to improve productivity and quality and project executer personnel with technical knowledge is also the key to on-time completion.

Besides the extension of duration factors explained above, coordination between personnel, education and experience of project staff and unexpected weather conditions have approximately the same mean of importance on the duration of construction projects. The mean of importance (ah) of coordination between personnel and education and experience of project staff were calculated as 4.2 and the mean of importance of unexpected weather conditions was calculated as 4.15 out of 5. As it can be seen, 4.15 and 4.2 are so close to 4 which represents important according to the Likert Scale. If a company is newly established and the staff are being changed continuously, the effect of bad coordination between personnel on duration of construction projects may be high. It should also not be neglected that policy of company can affect the personnel socially and psychologically. For example, if the payments of personnel are not on regular basis and there are problems in obtaining work permissions, motivation of personnel is naturally subject to become lower and thus the coordination of personnel among themselves is lowered. The results of questionnaire show that this is not the case for the companies took part in this survey because they are not newly established and employers appreciate the fact that personnel motivation is the key to success. Apart from motivation of the staff, the experience of the project staff should be high enough so that project is managed efficiently. If the project staff have reliable experience, mistakes can be minimized due to previous experiences. In addition, project staff can give advice to the controller to take precautions on the possible problems that may occur on site. Weather is another factor where work schedule can be hindered, but as it looks like, this factor is not with a great effect since there are no extreme weather conditions in Cyprus. However, this does not mean to take the weather guaranteed and some precautions should be taken before starting construction to prevent any delays and risk.

Improperly configured site consultancy, changes due to design error, disagreements between owner, contractor or subcontractor and slow decision making have approximately the same level of effect on duration of contruction projects. As can be seen from figure 45, improperly configured site consultancy has the mean of importance of 4.1. Changes due to design errors, disaggrements between owner, contractor or subcontractor and slow decision making have the same mean of importance of 4.05 which is almost 4. Therefore, if there is no effective consultation service and if there is no effective control on the site, workers might choose an alternative way without considering the consequences it causes to the details of project. In the end, work produced in an alternative way may not be in parallel with specifications. Therefore, if project is not controlled regularly, if there is design error and if there is disagreement between project parties, it will result in extension in the time of the contruction projects.

To sum up, coordination of all parties in harmony in construction projects should be provided at briefing stage. For example, as in our case, if BIM is used, all parties are expected to work on the same model as mentioned above paragraphs and if there is any change, the change can be modified automatically through the software.

Incorrect calculations of material amounts which has the mean of importance as 3.8 out of 5 and inadequacy of materials that has the mean of importance as 3.6 are exist the region between medium and important. Since materials are ordered according to calculated amounts, if material estimations are done correcty and ordered on time, these problems are not faced. On the contrary, when wrong amounts are ordered, the project stops, then correct amounts are ordered, which causes delay in completion time. Not to mention that, there may be delay in supplying materials either because the suppliers are busy or they don’t have the materials at that particular moment.

Last but not least, it can be seen from the survey results that, both of complexity of project and vehicle problems have the mean of importance as 3.2 out of 5. In addition, 15% of the twenty construction companies answered that it is very important and according to 10% of the companies vehicle problems are very important. Therefore, since score of 3 represents the medium effect, complexity of project and vehicle problems have the medium effect on project duration. In North Cyprus, there are no many complex projects. When there are complex projects, engineers from different disciplines work on same project such as hydraulic, geotechnical, electronic and civil engineers but this coordination of different disciplines may create delay problems. Also, vehicle problems are not significant in North Cyprus because there are no complex projects and the vehicles and machinery used in the simpler projects are mostly similar to each other. Once there is a problem with the vehicles or machinery, they can easily be substituted so that cause of delay in projects is not significant.

5.4.2 Factors Affecting Reworks in Construction Projects

Rework is one of the problem that can arise during construction of the projects due to some reasons and questionnaire among twenty construction companies was conducted in order to measure the rework factors in North Cyprus. Reworks may arise due to some reasons which are related with the design or they may arise when construction starts. Inexperienced subcontractor and workmanship, education and experiences of project staff, changing demands of clients, changes due to design errors, communication between personnel, application error due to misunderstanding of project and complexity of project are major reasons of reworks in construction. Therefore construction companies were asked to evaluate these factors and these factors were analyzed whether they can be solved with BIM technology or not. Result data was entered into Microsoft Excel. Table 21 shows the number of attributes who rated the rework factors from 1 (not important) to 5 (very important).

Table 21. Number of attributes who rated the rework factors from 1 to 5

Criteria and Attributes	#5 Very Important	#4 Important	#3 Medium	#2 Slightly Important	#1 Not Important
Inexperienced subcontactor	10	3	6	1	0
Inexperienced workmanship	10	5	3	2	0
Experince and education of project staff	6	11	2	1	0
Clients' changing demands	18	2	0	0	0
Changes due to design errors	11	3	5	1	0
Communication between personnel	6	8	6	0	0
Application error due to misunderstanding of project	8	5	6	1	0
Complexity of work	3	5	10	2	0

#1, not important; 2, slightly important; 3, medium; 4, important; 5, very important.

Then after finding n values for each attributes, the mean of importance of attributes (a_h), weight of attributes (w_h) and weight index of attributes (Wi_h) were calculated by using equation 1, equation 2 and equation 3 that were provided at methodology part. Table 22 summarizes the details about the calculated a_h, w_h and Wi_h values.

Table 22. Mean of importance (a_h), weight (w_h) and weight index of attributes (Wi_h)

Criteria and Attributes	**Mean (a_h)** (Eq.1)	**Weight (w_h)** (Eq.2)	**Weight Index (Wi_h)** (Eq.3)
Inexperienced subcontactor	4.1	0.125	0.836
Inexperienced workmanship	4.15	0.126	0.847
Experince and education of project staff	4.1	0.125	0.836
Clients' changing demands	4.9	0.149	1.000
Changes due to design errors	4.2	0.128	0.857
Communication between personnel	4	0.122	0.816
Application error due to misunderstanding of project	4	0.122	0.816
Complexity of work	3.45	0.105	0.704

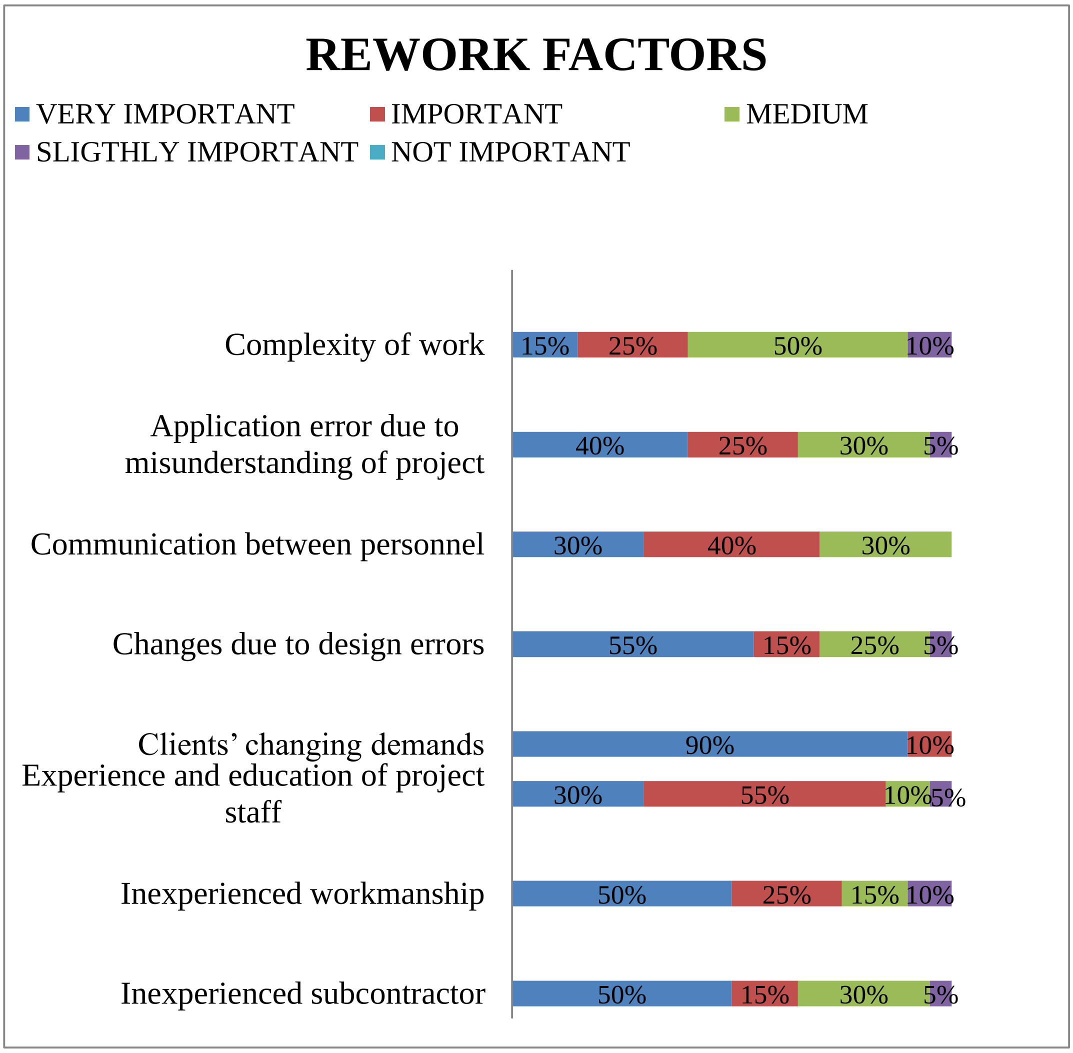

Figure 44. Calculated percentages of the rework factors according to questionnaire results

Percentages of all rework factors among twenty construction companies were calculated to determine percentages of very important, important, medium, slightly important and not important and bar chart of the rework factors are given in figure 44 with the percentages.

In addition, figure 45 shows the bar chart of the mean of importance for all factors that cause reworks during construction. From the questionnaire results, it can be concluded that the most important reason is changing demands of clients during construction, as stated many times before in the thesis.

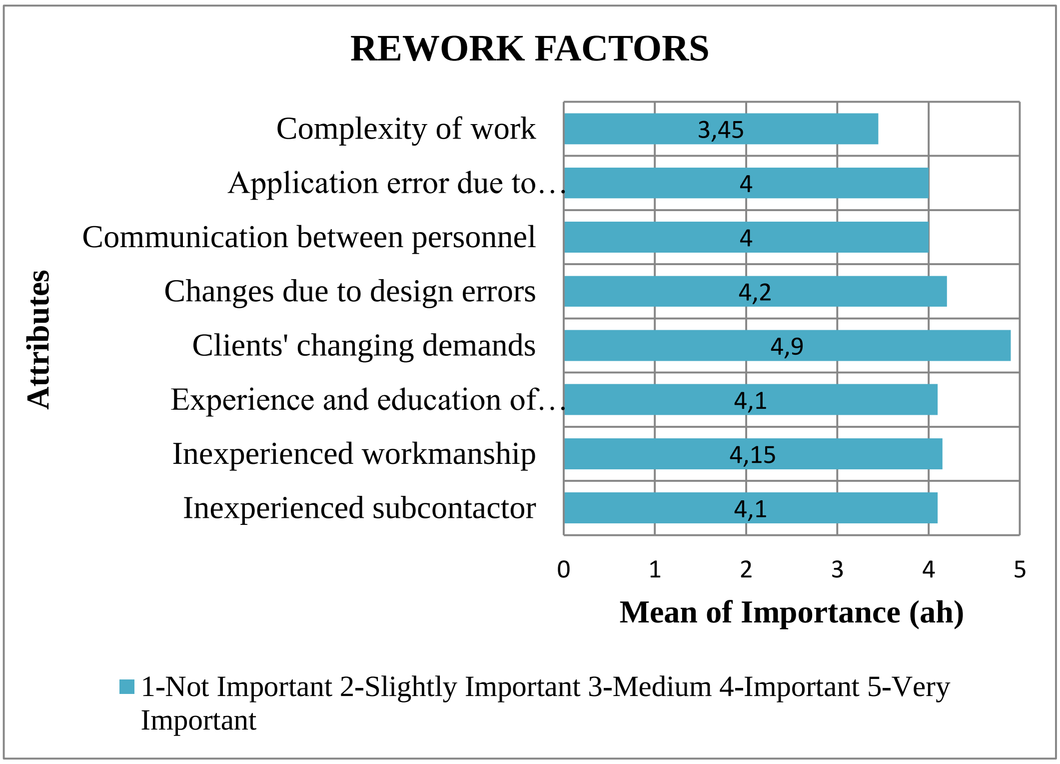

Figure 45. Representation of factors with bar chart

As the extension of duration factors, changing demands of clients were the most important reason of reworks because 90% of the construction companies answered that it is very important. In addition, it has a mean of importance as 4.9 which is approximately 5 where 5 represents very important according to Likert Scale. Therefore, clients' changing demands especially last minute changes are the most important factor that increases the possibility of rework (Love et al., 1998b). Changing demands of clients cause an increase in the rate of occurence of reworks and an extension of duration; both in turn leads to extra cost. Generally, it is difficult for the client to imagine and visualize the end product thus client may not have a clear understanding of the project from two dimensional drawings so that end product may not meet the need of clients (Lertlakkhanakul, Choi, & Kim, 2008). In this case, BIM can be an effective alternative to minimize this problem because visualization feature of BIM increases understanding of the project by clients (Azhar, Hein and Sketo, 2010). Therefore, if designer produces three dimensional intelligent BIM models in the beginning, client can have a clear understanding of the project due to visualization ability of BIM to show the inside building with sections. In the end, clients have a clear idea about the end product and last minute changes demanded by the client can be minimized by doing necessary design changes before moving to the site. In North Cyprus, the questionnaire results showed that 35% of companies always use 3D models and 35% of companies do not use 3D modeling at all. However, 35% of companies use 3D models not for BIM purposes. They use 3D models but not BIM models just to show the appearance of the end product, not other sections in details. Using BIM models are expected to result in increasing client satisfaction and decreasing delays in construction projects and competitiveness in the sector may also be increased by providing better services with BIM.

Following the importance of changing demands of clients on reworks, changes due to design errors have a role in increasing the rate of occurence of reworks because 55% of twenty construction companies mentioned that it is very important factor on reworks and it has a mean of importance as 4.2 out of 5 where 5 is very important. According to the open-ended questions of the questionnaire, usually, change in the places of doors and windows, change in the dimensions of doors and windows, change in the architectural plan, change on interior walls, addition of extra rooms, enlargment of balconies are rework examples that are being faced in construction projects in North Cyprus.

Not to mention that inexperienced workmanship, inexperienced subcontractor and experience and education of project staff have approximately same importance level on the occurence of reworks. The mean of importance of inexperienced workmanship was calculated as 4.15 and both experience and education of project staff and inexperienced subcontractor have the mean of importance as 4.1 which are close to score of 4 that represents important. Therefore, experienced workers should be employed to improve productivity and quality that will prevent reworks. Also as it was mentioned before, if the project staff have the relevant experience and knowledge, possible problems that may be faced during construction phase can be predicted and necessary precautions can be taken to prevent possible problems and reworks. A striking result that can also be drawn from the open-ended questions of questionnaire is that, firms want their workers to have relevant experience to use materials and machinery without damaging them on the construction site otherwise delays and increase in the cost of the project can be seen.

Application error due to miscommunication and misunderstanding between personnel are less important on the occurence of reworks than the factors that were mentioned above. 40% of the companies answered that application error due to misunderstanding of the project is very important and its mean of importance was calculated as 4. Also, according to the 30% of the companies, communication between personnel is very important and it has mean of importance as 4 that shows both of the factors are important. Therefore, in order to minimize application errors, it is useful for workers to see the project from 3D models before starting construction. The communication between the parties can reduce reworks and better information sharing can be obtained by BIM since all parties work on the same model (Eastman, 1999).

As briefly mentioned above, the complexity of the project which has the mean of importance as 3.45 is between medium and important and just 15% of the twenty construction companies answered that it is very important since there are no complex projects in North Cyprus.

Besides the mentioned reasons, there are also other factors that cause reworks in construction projects. According to the open-ended questions in the questionnaire, reworks can occur due to the carrying out the works in another way than as it is indicated on the plan, thus regular supervision on the site is a way to reduce reworks. Before starting construction of project on the site, its constructibility should be evaluated and the project should be designed and constructed according to that. Also, when the project is prepared, project team must study the project well.

Moreover, when materials are supplied to the site, quantity and type of materials should be checked whether their amounts, types and qualitiesmeet the required levels or not. Using wrong materials, wrong qualities and wrong amounts give a way to reworks.

There are some examples of reworks in North Cyprus. According to the questionnaire, companies told that different demands of clients are the reason of reworks such as when the construction is about to get finished, the client tries to choose the cheapest material to decrease the cost of the project. Another example is, enlarging and reducing the areas in the projects due to the reason of cost or aesthetics.

Results show that lack of material availability in the industry causes the client to go for another type of materials that leads increased occurence of reworks. Another example for reworks comes from miscommunication and lack of coordination between electrical, civil and mechanical engineers.

Strengthening columns and beams by increasing dimensions and adding reinforcement are other examples of why reworks can occur.

When reworks occur in construction projects due to the factors that are mentioned above, cost and the duration of the project is increased. Solution is to use BIM technology so that coordination between parties is expected be improved since all parties work on the same model. The client satisfaction is expected to be increase by using visualization at the beginning of project. Application errors due to misunderstanding of project can be decreased by better understanding the project with visualization feature of BIM and all of the factors that are mentioned above are expected to be improved or turned to positive by using BIM.

Chapter 6

CONCLUSION

6.1 Conclusion

Construction projects are getting more complex day by day and it can be difficult to manage them with traditional methods. At briefing stage of construction projects, clients define their needs for project and designer tries to design project that meet with client requirements. However, with traditional methods (2D Drafting), producing project drawings take more time and may not meet the client requirements. Therefore, from the findings, it can be concluded that four architects spent Autodesk Revit Architecture produces a project drawings faster than AutoCAD because overall duration to prepare project drawings in Autodesk Revit Architecture is 3.4 times shorter than the duration in AutoCAD although all four architects have prepared projects in AutoCAD more than in Autodesk Revit Architecture in the past. From the interview results, when standard deviations are analysed, the higher $\pm$ σ variation in duration obtained from the 2D drafting method indicates that experience could decrease the duration with a high amount that means 2D drafting method is found to be more difficult to learn when compared with BIM solution because $\pm$ σ variation of BIM is lot less than 2D drafting. Autodesk Revit Architecture enables the designer to generate plans, sections, views, three dimensional views of models quickly and when any change is done in any object, it is updated automatically in other plans, views and sections. This feature of Autodesk Revit Architecture eases the construction documentation process. Also, when any change is done in any of the plans in AutoCAD, the same change should be updated in all other views and sections one by one and that may cause errors in drawings.

Therefore, it can easily be said that, not only using Autodesk Revit Architecture is faster than AutoCAD in terms of producing project drawings but also Autodesk Revit Architecture provides a better understanding of what will be the end product because the clients describe their demands and requests about the project at a briefing stage and the project is designed towards the demands of the client. In this process, if the design is prepared using two dimensional drawings, client may not clearly understand the whole project and the small details because clients may not be a technical people who can read and understand two dimensional drawings. This procedure is likely to lead to reworks when construction starts.

BIM technology also enables to obtain quantities automatically and faster from software. Autodesk Quantity Takeoff which is one of practical BIM software and Autodesk Revit Architecture were used in this thesis to obtain architectural bill of quantities. As it can be seen from the results, it is a faster way than doing manual calculations. Material takeoff feature of BIM software helps to extract quantities without calculating quantities manually and it also enables time saving and more accurate results. For example, quantities were extracted from both Autodesk Revit Architecture and Autodesk Quantity Takeoff in 1 minute but duration of bill of quantity calculation by hand of four civil engineers on average was 178.25 minutes. That means Autodesk Quantity Takoeff and Autodesk Revit Architecture are almost 178.25 times more time-efficient than manual calculations. On the other hand, when the accuracy of plaster/painting calculations obtained from Autodesk Revit Architecture was compared with the accuracy of manual calculations of four civil engineers, the accuracy of manual calculations was found to be 99.37% whereas the accuracy of the automatic takeoff was 100%. In the case of floor area, the accuracy of manually calculated floor quantity by four civil engineers was found to be 93.42% whereas the accuracy of automatic takeoff was 100%. It can be concluded that there is possibility of doing mathematical errors during hand calculations but software directly gives the quantity and there is no possibility of doing mathematical errors. Therefore, it is believed that the accuracy of results is high in BIM as the mathematical errors emerging from manual calculations do not occur in the software.

In addition, construction duration may extend due to some reasons and reworks may arise during construction process. In North Cyprus, according to the questionnaire results, construction companies generally use project planning software because 35% of twenty construction companies answered that they use project planning software always. Moreover, according to questionnaire survey, most of the companies (30% of companies) answered that average delay amount is between 26% and 30%. Also, most of the construction companies (50% of twenty construction companies) that participated questionnaire have the type of bid, design and built. There are several reasons of extension of duration and according to the questionnaire survey among twenty construction companies it was found out changing demands of clients is the most important factor that has the mean of importance as 4.8 out of 5 where score of 5 represents very important according to the Likert Scale.

Furthermore, rework factors were also measured among construction companies and changing demands of clients is again the the most important factor that cause reworks during construction with the mean of importance 4.9 out of 5 that represents very important according to the Likert Scale. Furthermore, according to the most companies (30% of the companies) average rework amount varies from 31% to 40%.

BIM technology has a great potential to solve many problems that are faced in all stages of construction projects. It can minimize some of the factors that affect both on time completion and reworks and prevent extension of duration of projects. In the construction sector, generally, in addition to that, it is wise for construction companies to use construction planning software to reduce delays and to reduce extension of duration.

To sum up, using BIM in construction projects reduces reworks, increases client satisfaction, enables to finish the project within budget, detects collisions, improves communication between parties, provides better understanding of project due to visualization and provides faster and more accurate quantity takeoff. However, in order to apply this new technology, necessary software must be bought and installed and staff should be trained to learn this BIM software. Eventually this technology helps to increase the competitiveness of the company in the market.

REFERENCES

Alshawi, B., & Ingirige, B. (2003). *Web-Enabled Project Management an Emerging Paradigm in Construction*. Automation in Construction. 12 (4), 349–364.

Arayıcı, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., & O'Reilly, K. (2011). *BIM Adoption and Implementation for Architectural Practices*, 7-25.

Associated General Contractors of America. (2005). *The Contractor's Guide to BIM*, 1st ed. AGC Research Foundation, Las Vegas, NV.

Aouad, G., Lee, A., & Wu, S. (2006). *Constructing the Future: nD Modeling*. Taylor and Francis, London.

Autodesk Inc. (2005a). *Parametric Building Modeling: BIM's Foundation*. Retrieved March 25, 2006 from http://images.autodesk.com/adsk/files/Revit_BIM_Parametric_Building_Modeling_Jun05.pdf

Autodesk, 2007. *White Paper on Bim and Cost Estimating* [online]. Available at: http://www.consortech.com/bim2/documents/BIM_cost_estimating_EN.pdf [Accessed 28 April 2013].

Autodesk, Inc. (2008). *The Five Fallacies of BIM.* White paper. <http://static.ziftsolutions.com/files/8a7c9fef2693aa1e0126d2961da1084b> (August, 2009).

Ashcraft, H. (2007). *Building Information Modelling – A Framework for Collaboration, Construction Lawyer*, vol. 28, Number 3, accessed: February 2010, <http://hbmvr.com/docs/articles/bim_building_information_modeling_a_framework_for_collaboration.pdf>

Azhar, S., Hein, M., & Sketo, B. *Building Information Modeling (BIM): Benefits, Risks and Challenges.* Auburn University, Auburn, Alabama.

Baalousha, Y.M. (2011). *An Integrated Web-Based Data Warehouse & Artificial Neural Networks for Unit Price Analysis with Inflation Adjustment.* Eastern Mediterranean University, North Cyprus.

Baldwin, M., & Jellings, J. (2009b). *Quantity Surveying - A Time Consuming Job*. BIM Journal, 1(11).

Bazjanac, V. (2006). *Virtual Building Environments (VBE) – Applying Information Modeling to Buildings* [WWW document].URL http://repositories.cdlib.org/lbnl/LBNL-56072

Bedrick, J. (2005). *BIM and Process Improvement [WWW document]*. URL http://aecbytes.com/viewpoint/issue_20_pr.htm

Bennett, S. (2008). *BIM Can Boost Productivity*. Daily Journal of Commerce, Portland, Oregon.

Bowling, A. (1997). *Research Methods in Health.* Open University Press, Buckingham.

Brown, J. D. (2001). *Using Surveys in Language Programs:* Cambridge University Press.

Bryde, D., Broquetas, M., & Volm, J.M. (2012). *The Project Benefits of Building Information Modelling (BIM).* International Journal of Project Management xx (2013) xxx-xxx.

Burns, N., & Grove, S.K. (1997). *The Practice of Nursing Research Conduct, Critique, & Utilization*. W.B. Saunders and Co., Philadelphia.

Bynum, P., Issa, R.A.A., & Olbina, S. (2013). *Building Information Modeling in Support of Sustainable Design and Construction.* Journal of Construction Engineering and Management. 139, 24-34.

Card S.K., Mackinlay J.D., & Shneiderman B. (1999). *Information Visualization*, Morgan Kaufman Publishers, Inc., San Francisco, CA .

Chan, A.P.C., Scott, D., & Chan, A.P.L. (2004). *Factors Affecting the Success of A Construction Project.* Journal of Construction Engineering and Management. 130, 153–155.

Coates, P., Arayici, Y., Koskela, L., Kagioglou, M., Usher, C. & O'Reilly, K. (2010). *The Key Performance Indicators of the BIM Implementation Process.* Proceedings of the ICCBE Conference, June 30, Nottingham.

Condit, G. (2006). *Complex Projects Call for Virtual Construction [WWW document]*. URL http://www.djc.com/news/co/11184025.html

CRC Construction Innovation. (2007). *Adopting BIM for Facilities Management: Solutions for Managing the Sydney Opera House,* Cooperative Research Center for Construction Innovation, Brisbane, Australia.

Çelik, T. (2007). *Introduction to Course and Bill of Quantities*. GaziMağusa: Eastern Mediterranean University.

Davis, K., & Ledbetter, W.B., (1989). *Measuring Design and Construction Quality Costs.* Source Document No.3, Construction Industry Institute USA.

Douglas, C. E. (2010). *The Effects of Building Information Modeling on Construction. Thesis (Masters).* Faculty of civil and environmental engineering, University of Maryland, Baltimore, MD, USA.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors*. Wiley, New Jersey.

Eastman, C. (1999). *Building Product Models: Computer Environments Support Design and Construction*, CRC Press LLC, Florida.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2008). *BIM handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, Wiley, Hoboken, NJ.

Egan, J. (1998). *Rethinking Construction. Report from the Construction Task Force,* Department of the Environment, Transport and Regions, UK.

Ekanayake, L. L., & Ofori, G. (2004). *Building Waste Assessment Score: Design-Based Tool*, 851-861, Singapore.

Emmerson, H. (1962). *Studies of Problems Before the Construction Industries*, HMSO, London.

Firat, C. E. et al., 2010. *Quantity Take-Off In Model-Based Systems.* Kairo, s.n.

Gao, Z., Walters, R. C., Jaselskis, E. J., & Wipf, T. J. (2006). *Approaches to Improving The Quality of Construction Drawings From Owner's Perspective*. J. Constr. Eng. Manage. 132(11), 1187–1192.

Gee, C. 2010. *The Influence of Building Information Modelling on the Quantity Surveying Profession*. Undergraduate Dissertation. University of Pretoria.

Grilo, A., & Jardim-Goncalves, R. (2010). *Value Proposition on Interoperability of BIM And Collaborative Working Environments*. Automation in Construction. 19 (5), 522–530.

Hammarlund, Y., & Josephson, P. E. (1991). *Sources of Quality Failures in Building. European Symposium on Management, Quality and Economics in Housing and Other Building Sectors.* Lisbon, Portugal, September 30th - October 4th, pp 671-679.

Hardin, B. (2009). *BIM and Construction Management: Proven Tools, Methods, and Workflows,* Wiley Publishing, Inc., Indianapolis, IN.

Hartmann, T., & Fischer, M. (2007). *Supporting the Constructability Review with 3D/4D Models.* Build. Res. Inf., 35 (1), 70–80.

Hartmann, T., Gao, J., & Fischer, M. (2008). *Areas of Application for 3D and 4D Models on Construction Projects.* Journal of Construction Engineering and Management.

Hergünsel, M.F. (2011). *Benefits of Building Information Modeling for Construction Managers and BIM Based Scheduling. Thesis (Masters).* Faculty of Civil Engineering. Worcester Polytechnic Institute.

Holness & Gordon V.R. (2008*). Building Information Modeling Gaining Momentum.* ASHRAE Journal. 28-40.

Howell, I., & Batcheler, B. *Building Information Modeling Two Years Later-Huge Potential, Some Success and Several Limitations.*

Hunt, C. (2005). *eArchitect: Revit Finally Comes of Age.* [Building Design].URL http://global.factiva.com/en/arch/print_results.asp

Jayasena, H.S., & Wijayakumar, M. (2013). *Automation of BIM Quantity Takeoff to Suit QS's Requirements.* The Second World Construction Symposium. University of Moratuwa, Sri Lanka.

Jones, M. C., & Rattray, J. (2007). *Essential Elements of Questionnaire Design and Development.* Journal of Clinical Nursing. 16, 234-243.

Josephson, P. E., & Hammarlund, Y. (1996). *The Cost of Defects in Construction. Proceedings of the CIB-W65 International Symposium for the Organisation and Management of Construction:* Shaping Theory and Practice, Vol. 2, University of Strathclyde, Strathclyde, Scotland, UK.

Kamat, V.R., & Martinez, J.C. (2001). *Visualizing Simulated Construction Operations in 3D*. Journal of Computing in Civil Engineering. 15(4), 329-327.

Khemlani, L. (2006). *Visual Estimating: Extending BIM to Construction*. AECbytes, <http:// www.aecbytes.com/buildingthefuture/2006/VisualEstimating.html>

Khemlani, L. *AGC's Winter 2011 BIMForum, Part 1. AECbytes "Building the Future"* (2011). Web. 22 Mar. 2011. <aecbytes.com>.

Kim, S., Chin, S., Yook, S., Shin, T., Kim, Y., & Choi, C. (2009). *Automated BIM System for Building Interior to Improve Productivity of BIM-Based Quantity Take-Off*. 26th International Symposium on Automation and Robotics in Construction.

Kiviniemi, A. (2005). *Requirements Management Interface to Building Product Models*. Vtt Publications.

Kymmel, W. (2008). *Building Information Modeling: Planning and Managing Construction Projects with 4D and Simulatons*, McGraw-Hill.

Kymmell, W. (2000). *Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations*, McGraw-Hill Companies, Inc., Berkshire, UK.

Latham, M. (1994). *Constructing the Team: Joint Review of Procurement and Contractual Arrangements in the UK Construction Industry*, Department of the Environment, HMSO.

Lee, C. (2008). *BIM: Changing the AEC Industry*. PMI Global Congress 2008. Project Management Institute, Denver, Colorado, USA.

Lertlakkhanakul, J., Choi, J., & Kim, M. (2008). *Building Data Model and Simulation Platform for Spatial Interaction Management in Smart Home*. Automation in Construction, vol. 17, no. 8, pp. 948-957.

Love, P.E.D., Mandal, P., & Li, H. (1998a). *Determining the Causal Structure of Rework in Construction.* Construction Management and Economics.

Love, P.E.D., Smith, J., & Li, H. (1998b). *Benchmarking the Costs of Poor Quality in Construction: A Case Study*. Proceedings of the Second International and Fifth National Conference on Quality Management, Monash University, 9th–11th February Melbourne, Australia.

Love, P. E. D. (2002a). *Influence of Project Type and Procurement Method on Rework Costs in Building Construction Projects*. J.Constr. Eng. Manage. 128 (1), 18-29.

National Building Information Modeling Standard, Transforming the Building Supply Chain through Open and Interoperable Information Exchanges, version 1.0 — Part 1 — Overview, Principles and Methodologies; NBIS, 2007.

Love, P., Smith, J. & Li, H. *The Propagation of Rework Benchmark Metrics for Construction*. International Journal of Quality & Reliability Management, Vol 16 (7), pp.638658, http://www.emeraldinsight.com/Insight/ViewContentServlet?Filename=Published/EmeraldFullTextArticle/Pdf/0400160701.pdf (August 28, 2008).

Man, M. (2007). *BIM, Building Information Modeling and Estimation,* Stockholm: Byggteknik och design, Kungliga tekniska högskolan.

McKinney, K. & Fischer, M. (1998). *Generating, Evaluating and Visualizing Construction Schedules with CAD Tools*, Automation in Construction, *7(6):*433-447.

Meadati, P., & Irizarry, J. *BIM- A Knowledge Repository*. Southern Polytechnic State University, Georgia Institude of Technology, Georgia.

Mikael, B., & Frank, J. (2008). *Effektivare kalkylarbete med BIM?* Lund: Institutionen för Byggproduktion, Lunds Tekniska Högskola.

Monteiro, A., & Martins, J.P. (2012). *BIM Modeling for Contractors-Improving Model Takeoffs*. 29th International Conference, Beirut, Lebanon.

Post, N. M. (2006). *Team Members Seek Ways out of Building Modeling* [WWW document]. URL http://www.enr.com

Rajendran, S., & Clarke, B. (2011). *Safety Benefits and Opportunities*.

Sah, V., & Cory, C. (2009). *Building Information Modeling: An Academic Perspective*. Purdue University.

Saleh, M.A.E. *Automation of Quantity Surveying in Construction Projects*.

Sattineni, A., & Bradford, R.H. *Estimating with BIM: A Survey of us Construction Companies.* Auburn University, Auburn, USA.

Shen, Z., & Issa, R.R.A. (2010). *Quantitative Evaluation of the BIM-Assisted Construction Detailed Cost Estimates.* Papers in Construction Management.

Shen, W., & Shen, Q. (2011). *BIM-Based User Pre-Occupancy Evaluation Method For Supporting The Designer-Client Communication In Design Stage.* Management and Innovation for a Sustainable Built Environment, Amsterdam, The Netherlands.

Shneiderman, B., & Plaisant, C. (2005). *Designing the User Interface: Strategies for Effective Human-computer Interaction.* 4th ed., Pearson Education, Inc., Upper Saddle River, NJ.

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

Smith, S. (2008). *Bentley and Autodesk Announce Historic Interoperability Agreement. Bentley,*<http://www10.aeccafe.com/nbc/articles/view_article.php?articleid=567023 > (July, 2009).

Song, Y., and Chua, D. K. H. (2006). Modeling of Functional Construction Requirements for Constructability Analysis. *J. Constr. Eng. Manage.*, 132 (12), 1314–1326.

Staub, French, S., Fischer, M., Kunz, J., & Paulson, B. (2003a). *A Generic Feature-Driven Activity-Based Cost Estimation Process.* Adv.Eng. Inf., 17(1), 23–29.

Staub, French, S., Fischer, M., Kunz, J., and Paulson, B. (2003b). *An Ontology for Relating Features with Activities to Calculate Costs.* J. Comput. Civ. Eng. 17(4), 243–254.

Tiwari, S., Odelson, J., Watt, A., & Khanzode, A. (2009). *Model Based Estimating to Inform Target Value Design.* AEC bytes. Retrieved from http://www.aecbytes.com/buildingthefuture/2009/ModelBasedEstimating.html.

Viklund, F. (2010). *Model Based Quantity Take off Using BIM,* Stockholm: Avdelningen för Byggnadsteknik, Kungliga tekniska högskolan.

Wang, X., Truijens, M., Hou, L., Wang, Y., & Zhou, Y. (2014). *Integrating Augmented Reality with Building Information Modeling: Onsite construction process controlling for liquefied natural gas industry.* Automation in Construction 40, 96-105.

Whyte, J. (2002). *Virtual Reality and the Built Environment*. Architectural, Oxford, U.K.

Williams, M. (1996). *Graphical Simulation for Project Planning: 4Dplanner*. Proc., Computing in Civil Engineering, ASCE, Reston, Va. 404–409.

Williams, T. (2002). *Modelling Complex Projects.* Wiley, London, UK.

Won, J., Lee, G., Dossick, C., & Messner, J. (2013). *Where to Focus for Successful Adoption of Building Information Modeling within Organization*. J. Constr. Eng. Manage. 139.

Woo, J. H. (2011). *BIM and Pedagogical Challenges*. Western Illinois University, Macomb, IL.

Zhiliang, M. et al., (2010). *Framework Design for Bim-Based Construction Cost Estimating Software.* 27th International Conference, Cairo, Egypt, s.n.

APPENDICES

Appendix A: Interview among Architects

1. Select the suitable one.

❒Student ❒ Graduate

2. If are you working, how many years of construction experience do you have?

❒ 1-5 years ❒ 5-10 years ❒ 10 year and more

3. How can you rate your skill about using AutoCAD?

❒Advanced ❒ Intermediate ❒ Beginner

4. How can you rate your skill about using Autodesk Revit Architecture?

❒Advanced ❒ Intermediate ❒ Beginner

5. How many hours did it take to complete the project using AutoCAD?

……………………………………………

6. How many hours did it take to complete the project using Autodesk Revit Architecture?

……………………………………………

7. How many projects have you done by using AutoCAD?

……………………………………………

8. How many projects have you done by using Autodesk Revit Architecture?

……………………………………………

9. What do you think about the advantages or disadvantages of each program?

AutoCAD

Advantages:…………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

……….

Disadvantages:……………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

……….

Autodesk Revit Architecture

Advantages:………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

……….

Disadvantages:……………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

……….

10. What type of difficulties did you come across during project?

AutoCAD……………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

……….

Autodesk Revit Architecture…..

…………………………………………………………………………………………

…………………………………………………………………………………………

11. In order to do this project, did you go over other sources/materials/books/lectures/ anything?

AutoCAD………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

Autodesk Revit Architecture…………..

…………………………………………………………………………………………

…………………………………………………………………………………………

Appendix B: Survey among Construction Companies in North Cyprus

This questionnaire is for one of the master thesis in Eastern Mediterranean University:

1. Area of Expertise:

   Director□ Construction Manager□ Contractor□ Quantity Surveyor □

   Other…………….

2. Experience (Year):

   0-5□ 6-11□ 12-20□ 21-25□ 26-30□ more than 30□

3. Your duty in company: (You can select more than one)

   Owner□ Consultant□ Contractor□ Designer□ Other……………

4. Type of construction that your company builds:

   Residential Building □ Industrial Building □ Commercial□ Complex□

   Other…………

5. Are you applying construction planning (Microsoft Project) in projects?

   Always□ Usually □ Sometimes□ Never□

6. Are you using 3D models in projects?

   Always□ Usually □ Sometimes□ Never□

7. What is the average delay amount in projects?

0-5%□ 6-11%□ 12-20%□ 21-25%□ 26-30%□ 31-40%□ 41-47%□ 48-55%□ 56-61%□ 62-70%□ more than 70% □

8. What is the average rework amount in projects?

0-5%□ 6-11%□ 12-20%□ 21-25%□ 26-30%□ 31-40%□ 41-47%□ 48-55%□ 56-61%□ 62-70%□ more than 70% □

9. Rate the extension of duration factors:

Factors affect project duration	Very Important 5	Important 4	Medium 3	Slightly Important 2	Not Important 1
Unexpected weather conditions					
Improperly configured site consultancy					
Inexperienced subcontractor					
Inexperienced workmanship					
Reworks					
Education and experience of project staff					
Clients’ changing demands					
Coordination between personnel					
Changes due to design errors					
Late supply of material					
Incorrect calculation of material amounts					
Diminish of material					
Vehicle problems					
Disagreement between owner, contactor and subcontractor					
Complexity of work					
Slow decision making					

10. What can be the solutions of factors?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

11. What were the factors that cause duration problems according to your observations?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

12. Rate the rework factors:

Reworks	Very Important 5	Important 4	Medium 3	Slightly Important 2	Not Important 1
Inexperienced subcontractor					
Inexperienced workmanship					
Experience and education of project staff					
Clients' changing demands					
Changes due to design errors					
Communication between personnel					
Application error due to misundestanding of project					
Complexity of work					

13. What are the factors that affect rework apart from the factors that are mentioned above?

………………………………………………………………………………………

………………………………………………………………………………………

14. What type of reworks have you observed in your working life?

………………………………………………………………………………………

………………………………………………………………………………………