EVALUATION OF THE RELIABILITY OF BIM-BASED QUANTITY TAKE-OFF PROCESSES IN CONSTRUCTION PROJECTS

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submitted by **EMRE EROĞLU** in partial fulfillment of the requirements for the degree of **Master of Science in Civil Engineering Department, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** ________________

Prof. Dr. Ahmet Türer
Head of Department, **Civil Engineering** ________________

Assist. Prof. Dr. Aslı Akçamete Güngör
Supervisor, **Civil Engineering, METU** ________________

Examining Committee Members:

Prof. Dr. M. Talat Birgönül
Civil Engineering, METU ________________

Assist. Prof. Dr. Aslı Akçamete Güngör
Civil Engineering, METU ________________

Prof. Dr. İrem Dikmen Toker
Civil Engineering, METU ________________

Prof. Dr. Rıfat Sönmez
Civil Engineering, METU ________________

Assist. Prof. Dr. Saman Aminbakhsh
Civil Engineering, Atılım University ________________

Date: 11.09.2019

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Surname: Emre Eroğlu

Signature:

ABSTRACT

EVALUATION OF THE RELIABILITY OF BIM-BASED QUANTITY TAKE-OFF PROCESSES IN CONSTRUCTION PROJECTS

Eroğlu, Emre
Master of Science, Civil Engineering
Supervisor: Assist. Prof. Dr. Aslı Akçamete Güngör

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Quantity take-off (QTO) process is a significant part of construction projects. Outputs of this process are used in many phases of the projects such as resource planning, scheduling, budgeting etc. Commonly, quantities are calculated by using 2D CAD drawings and CAD tools but this process requires too much time and effort as well as it is prone to errors due to numerous variables. For instance, there is a risk of double counting, missing elements, probable errors when moving data between 2D drawings. Nowadays, Building Information Modeling (BIM) software programs are started being widely used as an alternative to the traditional methods for quantity take-off process. Studies in literature show that BIM ensures benefits in terms of time and accuracy of quantities due to its automated processes. However, studies commonly concentrate on acquiring quantities in standard conditions and there is not enough research regarding challenges in obtaining quantities of some problematic construction items such as formwork. Therefore, reliability of quantities extracted from BIM models is still a research subject. For this purpose, a case study is carried out by modeling selected construction items of a building with Autodesk Revit program and the quantities obtained are compared with the quantities extracted from Allplan model which was created by a construction company. Results indicate that formwork area quantities obtained from Revit by using a formwork area tool is not reliable however quantities of other items considered in the scope of this study which are obtained from Revit and Allplan models are consistent when appropriate modeling approaches for QTO are implemented. The modeling approaches required for different construction items and detailed analyses of QTO results are contributions of this study.

Keywords: Building Information Modeling, Quantity Take-off, Construction Projects, Cost Estimation, Project Management

ÖZ

İNŞAAT PROJELERİNDE YAPI BİLGİ MODELLEME TABANLI METRAJ ÇIKARIM SÜREÇLERİNİN GÜVENİLİRLİĞİNİN DEĞERLENDİRİLMESİ

Eroğlu, Emre
Yüksek Lisans, İnşaat Mühendisliği
Tez Danışmanı: Dr. Öğr. Üyesi Aslı Akçamete Güngör

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Metraj çıkarım süreci, inşaat projelerinin önemli süreçlerinden biridir. Bu sürecin çıktıları kaynak planlama, iş programı oluşturma, bütçeleme gibi birçok aşamada kullanılmaktadır. Genel olarak metrajlar, bilgisayar destekli çizilen iki boyutlu projeler ve diğer yardımcı bilgisayar programları ile hesaplanmaktadır. Bu süreç çok fazla zaman ve çaba gerektirmektedir ve çok fazla değişken bulunması nedeniyle hataya açıktır. Örneğin; çift sayma, eleman unutma ve iki boyutlu projeler arasında veri taşırken ortaya çıkabilecek diğer olası hatalar bu sürecin risklerindendir. Günümüzde geleneksel metraj çıkarım yöntemlerine alternatif olarak, Yapı Bilgi Modellemesi (YBM) programları yaygın olarak kullanılmaya başlanmıştır. Literatürdeki çalışmalar, Yapı Bilgi Modellemesinin otomatik süreçlerinin zaman ve miktarların doğruluğu açısından fayda sağladığını göstermektedir. Ancak, yürütülen çalışmalar genelde standart durumlarda metraj temini üzerine yoğunlaşmıştır ve kalıp alanı çıkarımı gibi sorunlu metraj kalemleri üzerine yeterli sayıda çalışma bulunmamaktadır. Bu yüzden, YBM programları ile elde edilen metrajların güvenilirliği halen bir araştırma konusudur. Buna istinaden, bir binanın seçilen inşaat kalemleri Autodesk Revit programı yardımıyla modellenerek bir vaka çalışması yapılmış ve elde edilen metrajlar yüklenici firma tarafından Allplan programı ile oluşturulan modelden çıkarılan metrajlar ile karşılaştırılmıştır. Karşılaştırma sonucuna göre, Revit programı kapsamında kalıp alanı metraj çıkarımı için kullanılan eklenti ile elde edilen metrajların yeterince güvenilir olmadığı fakat metraj alımına uygun modelleme yöntemleri kullanıldığında, çalışma kapsamında değerlendirilen diğer inşaat kalemleri için hem Revit hem de Allplan programlarından elde edilen metrajların tutarlı olduğu sonucuna ulaşılmıştır. Bu çalışma, farklı inşaat kalemlerinin güvenilir metraj çıkarımı için gerekli modelleme yöntemlerini tartışarak ve metraj sonuçlarını detaylıca inceleyip karşılaştırarak literatüre katkı sağlamaktadır.

Anahtar Kelimeler: Yapı Bilgi Modellemesi, Metraj, İnşaat Projeleri, Maliyet Tahmini, Proje Yönetimi

Dedicated to my beloved family

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ABBREVIATIONS	
AEC	Architecture, Engineering and Construction
BIM	Building Information Modeling
BOQ	Bill of Quantities
CAD	Computer Aided Design
CIFE	Center for Integrated Facilities Engineering
GBA	Gross Building Area
NBIMS	National BIM Standard
ODHC	Oral and Dental Health Center
PVC	Polyvinyl Chloride
QTO	Quantity Take-Off

CHAPTER 1

INTRODUCTION

Cost estimation process has significant place for the construction projects due to its impacts on both budgeting and scheduling. Cost estimation process is performed at tendering stage; to prepare a competitive offer, before the construction stage; to check the quantities and the prices for the forecast of initial budget, and during the construction stage for supervising the project budget.

Shen and Issa (2010) stated that cost estimating is an important process for construction projects and since there is a need for time to visualize, understand, demystify the project and make calculations, the process requires significant amounts of time. The relationship between construction items should be found out in detail to reach detailed cost estimate. Shen and Issa (2010) also asserted that according to information attained in 2007 from Surety Information Office, poor cost estimates is one of the main reasons for construction companies' failure.

The companies in construction industry are constantly searching for more accurate, faster and easier ways of implementing cost estimation process due to its financial impacts on the projects or due to projects' financial limitations. Cost estimation process have two substantial steps, one of them is *acquiring quantities* and the other one is *pricing*. Although, pricing is one of the significant steps for cost estimation, it is impossible to make a reliable cost estimate without accurate quantities. Since quantities are directly acquired from drawings, the process requires extensive knowledge, experience, and diligence to reach a correct result.

The current approaches for quantity take-off (QTO) generally depend on manual calculations such as measuring lengths, heights, areas and volumes by the help of 2D CAD drawings. This approach requires too much time and effort. On the other hand, manual methods may inevitably lead to problems such as erroneous measurements and unobtrusive clashes.

A new approach named as BIM-based QTO is today's major inclination for the architecture, engineering and construction (AEC) industry. As Sattineni and Bradford II (2011) stated, BIM provides opportunity for construction companies to get detailed and accurate cost estimation together with reduction in time and cost spent for the process. However, there are still concerns regarding the accuracy of quantities obtained from BIM models, due to the shortage of agreed method statements about modeling, and inadequate implementation of BIM for different projects. Olatunji, Sher and Ogunsemi (2010) mentioned that although BIM ensures reduction in errors and conflicts, there is still a challenge in the adoption of BIM for construction projects due to the gap between automated process of BIM and estimation traditions. Therefore, in this study, reliability of the BIM based QTOs is scrutinized by implementing a case study with different BIM software tools to test and compare QTOs obtained through these tools. The achieved results are shared in detail in the following chapters.

1.1. Quantity Take-Off in Construction Projects

Cost estimation process is a pivotal part of construction projects and quantity surveying has a vital place in the execution of cost estimation process. Quantity take-off is essential for all phases of the project. Project team needs quantities for resource planning, scheduling, budgeting, cost control and various other work during the project.

Firat, Arditi, Hämäläinen, Stenstrand and Kiiras (2010) emphasized the importance of quantity surveying and pointed out that quantity take-off is fundamental for effective cost estimating, cost control, project scheduling and as a result for project management. Efficiency of projects and accuracy of schedules are directly related to factual and reliable quantities.

Likewise, Aram, Eastman and Sacks (2014) stated that cost estimation and the quantity take-off processes are crucial for the achievement of projects. Quantity take-off process is a predecessor (prior) activity of budgeting, bidding, production planning and budget control, therefore it is desired during the lifetime of the project.

Monteiro and Martins (2013) also mentioned that quantity take-off process is carried out during the lifecycle of the project. It is implemented at the beginning of project for preliminary cost estimate, at the tendering stage for the estimation of cost and duration, before the construction stage for planning of activities and at the construction stage for checking the cost of the project.

To sum up, quantity surveying is a fundamental part of the cost estimation process and accuracy of the quantity take-off is one of the major success measures of the estimation process. Therefore, it is obviously seen that obtaining accurate quantities is significant for construction projects and new approaches are constantly tested in the industry to achieve the best results.

1.2. Problem Statement

Cost estimation process can be described as forecasting costs by taking into account the limitations of the project, such as required materials, labor, and time constraints. For the construction industry, cost estimation is a significant part of other processes and it is crucial for both budgeting and scheduling (Sattineni & Bradford II, 2011).

Quantity surveying is fundamental element of cost estimation process. Until recently, quantities are calculated by means of traditional methods using 2D CAD drawings and CAD tools. Olsen and Taylor (2017) claimed that quantity take-off process executed with traditional methods requires too much time and effort as well as being prone to errors due to a large number variables involved in the process. When there are interpenetration of multiple elements, quantity take-off process with traditional methods becomes open to mistakes. For instance, there is a risk of double counting, missing elements, possibility of errors when moving data between 2D drawings. Since the estimators have to pay attention to all drawings in order not to disregard or double count the items, the process is becoming very time-consuming (Olsen & Taylor, 2017). When analyzed in terms of time, it is clearly seen that the traditional methods requires too much time. For instance; when there is a change in design, all the items affected from the design change should be examined in detail and because of that too much time is required for revising Bill of Quantities (BOQs).

Nowadays, BIM is being more widely used as an alternative to the traditional methods for quantity take-off process. There are numerous software programs such as Autodesk Revit, Allplan Architecture, Graphisoft ArchiCAD, Bentley, Vico, Autodesk Navisworks etc. Each program has its own method for modeling and obtaining quantity take-offs. Since programs have different working principles, the problems encountered while using them and the advantages they have also differs from each other. When considered in general, it is obvious that despite its advantageous aspects, BIM models have some deficiencies as well.

According to the studies in the literature, BIM use for the cost estimation processes ensures benefits in terms of time, accuracy and cost. Sattineni and Bradford II (2011) stated that BIM has ability to automate quantity take-off process and by this way, time and cost spent during process can be reduced. Azhar (2011) supported the idea that quantities can be automatically taken out from BIM model and QTO can be easily updated when any change occurs. Monteiro and Martins (2013) claimed that it is possible to attain detailed and accurate quantities with a simplest way by using BIM-based quantity take-off processes. The software programs are necessary to be used by people who are educated for these programs since the programs have some specific features to accelerate modeling process.

In the present days, it is agreed by the construction industry that quantities can be obtained easily and in a short time from the 3D building information models when compared with traditional methods. However, accuracy of the quantities extracted from these models is still a research subject. Each software program has its own features and methods, so it should be examined whether programs are providing accurate quantities for every single construction item or not. Olsen and Taylor (2017) argued that today, although BIM tools are widely used in projects, models created with BIM tools does not always ensure sufficient quality to take out proper quantities. Similarly, Olatunji et al. (2010) stated that BIM provides auto-calculated quantities according to the items which are considered only during modeling process. Therefore, some of the significant data regarding wastage, lapping and etc. may be missing in the model. Kulasekara, Jayasena and Ranadewa (2013) also argued that there is partially lack of confidence about the data acquired from BIM because of the encountered incompatibilities between the quantities obtained from BIM and traditional methods.

In conclusion, in order to evaluate the reliability of BIM based quantity take-off processes, the quantities extracted from BIM models need to be examined in terms of accuracy of the take-off results.

1.3. Research Questions

The aim of this thesis is to find answers to the following research questions:

RQ1. What *construction items* can be modeled and taken-off using a BIM tool?

RQ2. How *accurate* are the “quantity take-offs (QTO)” obtained using *different BIM tools*?

RQ2.1. What level of QTO accuracy can be achieved for *different construction items* in the cost estimate?

RQ2.2. What are the *reasons for differences* in the QTO of different tools?

RQ3. What *modeling approaches/techniques* are necessary to obtain accurate quantity take-offs?

1.4. Purpose of the Study

The purpose of this thesis is to evaluate the reliability of BIM based quantity surveying processes. Towards this purpose, BIM based quantity take-off processes are implemented with two different BIM tools which are named as Autodesk Revit and Allplan. The quantities extracted from two different models of the same building are compared, the differences are scrutinized in detail, the reasons of the differences are investigated, and the accuracy of the results is examined by making some manual calculations.

Another objective is to determine the limitations of BIM based quantity take-off processes. By this way, the quantities of which construction items can be smoothly obtained from BIM models are specified and the techniques needed to be applied to achieve proper quantities are determined.

1.5. Scope of the Study

This study focuses on evaluation of the reliability of quantities obtained from models created with two different BIM tools. For this purpose, a reinforced concrete building project is chosen and main structural and architectural construction items were selected to be modeled and then quantities of these items obtained from two different models were compared and differences were examined in detail.

Thesis chapters are organized as follows:

Chapter 1 introduces the problems in BIM based quantity take-off processes, research questions, objectives and scope of this thesis.

Chapter 2 presents literature review on quantity take-off methods such as traditional methods and BIM based methods, and BIM usage in construction industry. In this chapter, the way of implementing these methods as well as weak and strong sides of these methods are investigated. Previous case studies on BIM based QTO are examined.

Chapter 3 comprises the case study on BIM based quantity take-off with Autodesk Revit, information about the project, modeling methods and modeled construction items. This chapter also mentions major challenges and corresponding solutions.

Chapter 4 presents the results of the case study through comparisons between the QTOs obtained from two different BIM tools.

Chapter 5 concludes main research findings and discusses the limitations of the study and declares possible future research studies on this subject.

1.5.1. Elazığ ODHC Project Information

In this study, a medical building is selected as the case study project. The Oral and Dental Health Center (ODHC) building which is a part of Elazığ Integrated Health Campus, is located in Elazığ province of Turkey. Brief information about the project is given below:

Start Date: 03.10.2016
Finish Date: 02.09.2018
Gross Building Area (GBA): 13.048 m^2
Building Floor Area: 3.128,95 m^2
Number of Floors: 5 floors (Basement, Ground Floor and 3 floors)
Floor Height: 4.5 m
Number of Treatment Unit: 69 units

The building is constructed with reinforced concrete, exterior walls of the building are made out of cellular concrete. Insulation material used for the facade is rockwool. Windows located in the facade of building are made of aluminum frames and glass. Interior walls are cellular concrete and gypsum board. Metal doors, fire doors and wooden doors exists in the building. Floor covering materials are ceramic tile, mosaic tile, polyvinyl chloride (pvc), carpet, and parquet. Ceiling materials are gypsum board, rockwool, and metal.

A real photo of constructed building can be seen in Figure 1.1 below.

Figure 1.1. Elazığ ODHC Building View

1.5.2. BIM Software Programs Used for the Study

ODHC Building is modeled with Allplan 2018 by the BIM department of a construction company which is also the contractor of the project. During the construction period of the building, the quantities extracted from this model are used in related work such as resource planning, progress payments, etc. These quantities are also provided to us and are taken into account throughout this study.

In order to check the reliability of quantities and to make a comparison between models created with different BIM programs, selected construction items of the building are modeled with Autodesk Revit 2017 as well.

1.5.3. Evaluated Construction Items

In this study, only civil work of the building was included in the scope. Electrical and mechanical work were not taken into consideration. Within the civil work, only some construction items were selected to model with Autodesk Revit 2017 since too much time is required to model the whole construction items of the building. Required time for modeling, modeling scope of the available Allplan model, probability of providing quantities in other ways were taken into account during selection process of the construction items. For example, steel rebars whose quantities can be obtained with different software programs easily and which were not modeled in Allplan either were not selected for the scope of this study. A cost based study was conducted regarding the ratio of these modeled items according to the total budget of the building. Therefore, it can be seen how much of the total estimated cost of the project was modeled and evaluated in the scope of this study.

Reinforced concrete structure of the building was modeled but steel rebars were not taken into account in Revit. Exterior work of the building, such as exterior walls, facade insulation, exterior plastering, exterior windows and doors were modeled. However, interior work such as interior walls, plastering, flooring, and suspended ceiling were not modeled. Some other construction items such as ground work, infrastructure connections of the building, facade scaffolding which are not directly the part of the building were not taken into account either.

Table 1.1 shows the ratio of the modeled construction items' cost to building's entire (civil, mechanical, and electrical) cost. Table 1.2 shows the ratio of the modeled construction items' cost to building's civil cost. Table 1.3 shows the ratio of the modeled construction items' cost to building's civil cost of only the items selected for modeling scope. Ratios are shown according to cost of general construction item headlines.

Table 1.1. *Ratio of Modeled Construction Items' Cost to Building's Total Cost*

	According to Building's Entire Cost	
	Ratio of All Items	**Ratio of Modeled Items**
EARTHWORKS AND INSULATION	2.59%	0.00%
MAIN STRUCTURE WORK	20.21%	7.94%
WALL WORK	6.64%	0.89%
FLOOR WORK	3.44%	0.00%
CEILING WORK	1.68%	0.00%
ROOF WORK	1.32%	0.00%
FACADE WORK	2.71%	2.06%
DOORS AND WINDOWS	3.55%	1.19%
FITTINGS	0.08%	0.00%
MECHANICAL WORK	25.90%	0.00%
ELECTRICAL WORK	31.90%	0.00%
TOTAL	**100.00%**	**12.07%**

According to Table 1.1, ratio of modeled construction items' cost to building's entire cost is 12.07%. Since electrical and mechanical work are not in the scope of the study, 57.80% of building's cost that is not taken into consideration actually comes from such work.

Table 1.2. *Ratio of Modeled Construction Items' Cost to Building's Civil Cost*

	According to Building's Civil Cost	
	Ratio of All Items	**Ratio of Modeled Items**
EARTHWORKS AND INSULATION	6.13%	0.00%
MAIN STRUCTURE WORK	47.88%	18.80%
WALL WORK	15.73%	2.11%
FLOOR WORK	8.14%	0.00%
CEILING WORK	3.99%	0.00%
ROOF WORK	3.12%	0.00%
FACADE WORK	6.41%	4.87%
DOORS AND WINDOWS	8.40%	2.82%
FITTINGS	0.20%	0.00%
MECHANICAL WORK	0.00%	0.00%
ELECTRICAL WORK	0.00%	0.00%
TOTAL	**100.00%**	**28.60%**

According to Table 1.2, ratio of modeled construction items’ cost to building’s total civil cost is 28.60%. The major modeled part of the building is main structure elements that are reinforced concrete structures which has a ratio of %18.80.

Table 1.3. *Ratio of Modeled Construction Items’ Cost to Building’s Civil Cost in Modeling Scope*

	According to Building's Civil Cost in Modeling Scope	
	Ratio of All Items	**Ratio of Modeled Items**
EARTHWORKS AND INSULATION	2.53%	0.00%
MAIN STRUCTURE WORK	50.32%	19.76%
WALL WORK	16.53%	2.21%
FLOOR WORK	8.55%	0.00%
CEILING WORK	4.19%	0.00%
ROOF WORK	3.28%	0.00%
FACADE WORK	5.77%	5.12%
DOORS AND WINDOWS	8.83%	2.96%
FITTINGS	0.00%	0.00%
MECHANICAL WORK	0.00%	0.00%
ELECTRICAL WORK	0.00%	0.00%
TOTAL	**100.00%**	**30.05%**

According to Table 1.3, ratio of modeled construction items’ cost to building’s civil cost in modeling scope is 30.05%. Excavation and backfill work in earthworks, facade scaffolding work in facade work as well as mops and bins in fittings which are listed under civil work are considered as out of the modeling scope.

These summary tables demonstrates the ratio for main work titles, but the detailed tables regarding all work items are given in section 3.2.

CHAPTER 2

LITERATURE REVIEW

2.1. Quantity Take-off Overview

Quantity take-off is a detailed measurement of materials by measuring dimensions of building elements and calculating the features, such as area, volume etc. In order to form a quantity take-off, the estimator needs to work on blueprints, drawings or digital models. Generally, quantity take-off process is carried out by the contractor with the aid of 2D drawings prepared by architects (Olsen & Taylor, 2017). Estimators have to take into consideration each drawings and make the calculations carefully so as not to cause double-counting or omissions (Olsen & Taylor, 2017).

There are three type of quantity take-off methods which are commonly used in the construction industry. First one and also the traditional one is manual quantity take-off. This process is implemented only by hand with the help of physical drawings or blueprints, as commonly used in the past. Today, measurements are usually made on 2D or 3D CAD drawings which are created via programs such as Autodesk AutoCAD or Graphisoft ArchiCAD and then the quantities of the materials are again listed manually. Second one is digital quantity take-off which is the least used method in our country. In this method, drawings are uploaded into a program, the program analyzes the drawings and produces a list of materials. Third one is BIM based quantity take-off which is gaining popularity in recent years. In this method, the project is modeled by the help of a BIM tool and quantities are extracted automatically from the model.

Quantity take-off is a fundamental task of construction projects. It is a predecessor of several other tasks such as cost estimation, scheduling, resource planning, bidding and so on. Monteiro and Martins (2013) mentioned that quantity take-off is not a result of any processes, it is preliminary work of other processes. Therefore it is necessary during the lifecycle of a project. Aram et al. (2014) stated that in order to get efficient and accurate quantities, there is a need for estimators, who have experience on rules and processes about extracting information from projects through the projects' lifecycle.

Wijayakumar and Jayasena (2013) claimed that projects are becoming complex and besides, the expected duration for preparing documents, such as list of materials is becoming less due to the limited time and budget of the projects. Due to the dynamic nature of construction projects, quantities should be ready in time when it is necessary (Amiri, 2012). Therefore, it can be concluded that automation of quantity take-off processes in construction industry is inevitable as a remedy for these type of challenges.

2.2. Quantity Take-off Using CAD

Quantity Take-off using CAD drawings is a traditional and still widely used method in the construction industry. In this method, measurements are made by using computer aided design drawings, such as floor plans, wall plans, ceiling plans, elevations, facade appearances, sections and so on. Monteiro and Martins (2013) stated that in CAD based quantity take-off process, estimators have to interpret every complex condition like connections of structural elements, combination of walls and ceilings and make calculations with correct input data. Since the process is manual and depends on estimator's interpretation, it is obviously open to errors. Monteiro and Martins (2013) also summarized the significant drawbacks in this process from the studies about the disadvantages of manual quantity take-off practices. These drawbacks are "problems in detecting clashes, errors or omissions, representation of complex situations such as intersection points between many elements, and identification of cascading problems".

The time spent during the CAD based quantity take-off process can be clarified by looking at the three different phases involved which are understanding items and their relations, measuring dimensions by checking all related drawings, and computing the quantities like lengths, areas and volumes (Shen & Issa, 2010). The common idea about traditional quantity take-off process is that it takes too much time for both during the initial study and also while revising the first study when changes are needed. Sattineni and Bradford II (2011) stated that cost estimation is usually carried out only at the middle and the end of the project's each phase, due to the time needed for the process of quantity take-off which takes up to 3 weeks' time. Therefore, it is not possible to control the effect of design changes on cost, constantly.

Alder (2006) also stated that the traditional quantity take-off method is very time consuming, tedious and prone to errors especially for large projects. In order to avoid errors, such as double-counting or omissions, an estimator have to work with a well-organized and systematical methods and have to be careful while transferring measured quantities to other documents. Khosakitchalert, Yabuki and Fukuda (2018) asserted that quantity surveyors should have too much practice and experience so as to understand a set of 2D design drawings and to decide suitable method for each building item. Therefore, this process requires too much time and the data obtained from different surveyors may vary from each other.

In conclusion, it can be easily seen that nowadays, taking off quantities using CAD process, as performed traditionally, seems to fall short in responding the expectations of construction industry in terms of time and accuracy.

2.3. Definition of BIM

According to National BIM Standard (NBIMS 2012), BIM is defined as "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition".

Succar (2008) described BIM as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle".

Underwood and Isikdag (2010) stated that there is no concurrence about the definition of BIM and defined BIM as "a model of information about a building (or building project) that comprises complete and sufficient information to support all lifecycle processes and which can be interpreted directly by computer applications. It comprises information about the building itself as well as its components, and comprises information about properties such as function, shape, material and processes for the building life cycle".

Eastman, Teicholz, Sacks and Liston (2011) mentioned that BIM cannot be described only as a technology change, it is also a process change. BIM changes the implementation of all processes like understanding client's needs, analyzing design alternatives, cost, constructability etc. together with changing the creation process of visualization and drawings.

There are numerous ideas and evaluations regarding the usage of BIM. Succar (2009) summarized the association of these ideas regarding BIM terms as in Figure 2.1.

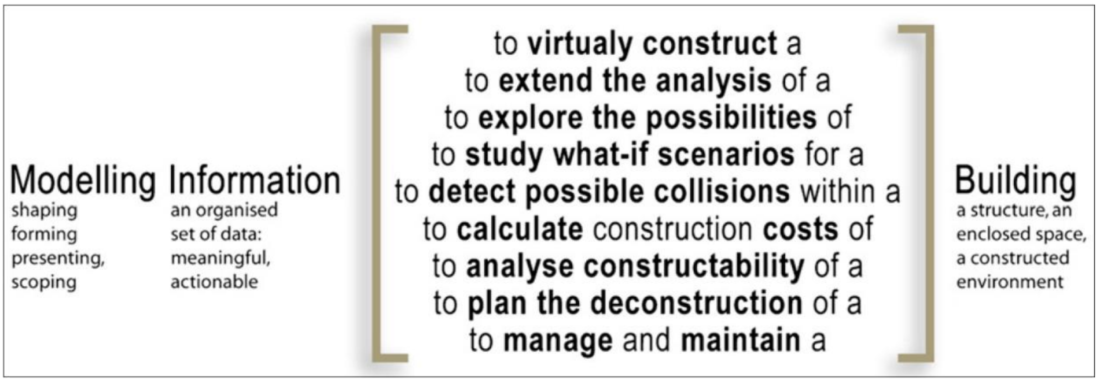


Figure 2.1. Some Common Connotations of Multiple BIM Terms
(Succar, 2009)

BIM is used in different phases of projects. The usage of BIM through the lifecycle of a building can be seen in Figure 2.2. As seen in this figure, BIM can be used from the beginning of the projects to its operation and demolition.

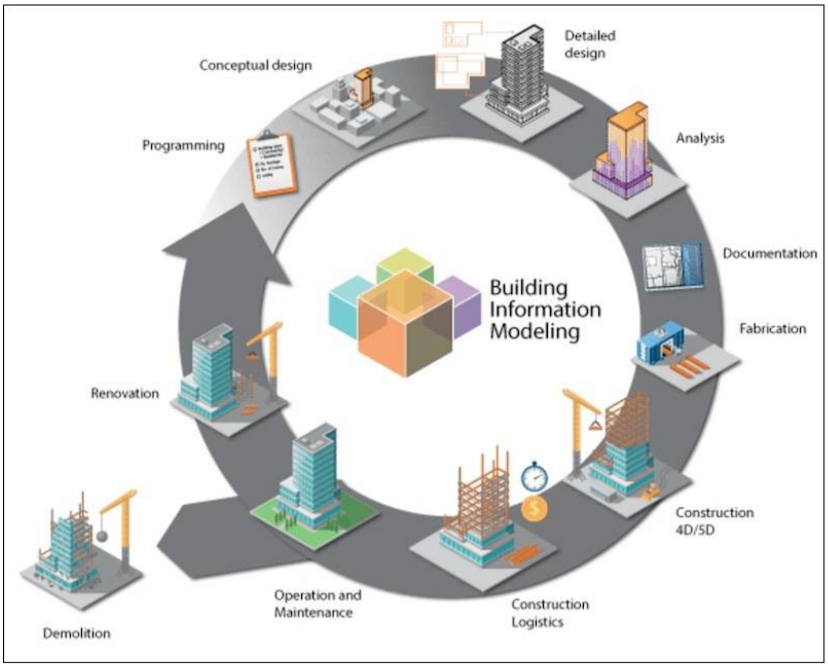


Figure 2.2. Usage of BIM throughout the Lifecycle of a Building
(Auci, Mundula & Quaquero, 2019)

2.4. Building Information Modeling (BIM) in Construction Industry

Construction projects are becoming complex and difficult to manage as time goes on and also construction industry is seeking for ways of improving processes such as quantity take-off. One of the current problem of construction industry is to obtain accurate quantities with a faster and easier method. In the recent years, BIM is becoming widespread in order to respond the needs of construction industry. According to Bryde, Broquetas and Volm (2013), the biggest change in terms of use of information technologies for the construction industry is proliferation of BIM.

In recent years, BIM awareness of people working in the AEC Industry is immensely increased. BIM is the latest technology for the construction industry and contributes to almost all of the processes of construction projects. In the beginning of BIM adoption, it was generally used for design coordination and visualization purposes of the projects. However, there are several other usage areas of BIM technology for the construction sector. Aladag, Demirdögen and Isık (2016) also asserted that BIM was mainly used as a visualization and organization instrument for project's participants in the past. However, BIM is now appraised as a process to develop the project's productivity during the life time of buildings. Therefore, it is seen that BIM can be used for different purposes such as "design and construction integration, optimization, risk evaluation, cost estimation, scheduling, communication, coordination, documentation, productivity, quality, safety, energy efficiency, project management and facility management".

Kulasekara et al. (2013) stated that BIM is the cutting-edge technology for the construction industry. A data including model is created with the help of BIM technology to use during the lifecycle of a project. This model enhances the communication and information sharing between the stakeholders of a project. Azhar and Nadeem (2008) emphasized that BIM gives opportunity to the stakeholders of project, such as architects, engineers and constructors, to envisage what is to be built and to remark probable problems regarding design, construction and operation.

According to Lu, Shen, Peng and Li (2012), BIM is variously realized as a virtual design model which can be used during the lifecycle of a project as a communication instrument between project's stakeholders, a platform which can be used for education in the academy, and also a learning tool for project members, who are working newly with each other, to know each other before the beginning of project on site.

Moreover, studies showed that BIM has lots of benefits for construction projects. According to the Azhar and Nadeem (2008), Building Information Modeling may provide solutions to the problems for decreasing cost, increasing productivity and quality and reducing delivery time, which are in the agenda of AEC Industry for a long while. Succar (2009) also supports the same ideas and claims that BIM is a beneficial tool to decrease the construction industry's disintegration, to develop project's productivity and to decrease the cost arising from the poor coordination of stakeholders. Amiri (2012) stated that according to the results of the study which is conducted by Gao and Fischer in 2008 about 32 major construction projects modeled with BIM, the benefits provided by BIM are "up to 40% elimination of unbudgeted change, cost estimation accuracy within 3%, up to 80% reduction in time taken to generate a cost estimate and up to 7% reduction in project time".

To sum up, it can be concluded that BIM technology is important for different stages of a construction projects and has an impact on the construction industry in many respects. In this study, BIM is going to be studied regarding the evaluation of quantity take-off and cost estimation processes.

2.5. BIM Based Quantity Take-off

Quantity take-off process is the main part of cost estimation process. BIM-based quantity take-off system is the latest technology for the construction sector. According to Monteiro and Martins (2013), automated quantity take-off process is one of the most useful advantage of BIM and since the required data are automatically bounded to the model, it is clear that BIM is fairly automated instrument.

BIM technology requires cultural change for the construction companies. Time is needed for adoption and education of the employees and also there is an investment cost for the software at the beginning of the process. For these reasons, a lot of construction companies are hesitating to use BIM technology for their projects (Olsen & Taylor, 2017). Most of the construction companies which are adapted to BIM technology, still do not use the automated quantity take-off processes of BIM programs since they don’t have educated estimators. Sattineni and Bradford II (2011) stated that although Building Information Modeling is a long-sought subject for the construction industry, there have been limited implementations for the quantity take-off processes.

BIM enhances collaboration between project stakeholders and provides better information sharing environment. Therefore, conflicts between project team are minimized and deficient and inadequate information are prevented. As a result of this, estimation process reveals faster, easier, and accurate results. According to the previous studies, there are explicit benefits of BIM based QTO, like reduction in time and cost as well as increase in accuracy. Olatunji et al. (2010) stated that since BIM facilitates data sharing among project’s participants, it hinders disagreements and incompetent data and hereby ensures more efficient quantity take-off process. Olsen and Taylor (2017) pointed out that models generated with BIM programs are intelligent and these intelligent models lead to enhance the accuracy of the estimate and decreases the time spent for acquiring quantity take-off. Kulasekara et al. (2013)

also supported the idea that by using BIM, quantity take-off process can be automated and therefore, it provides reduction in time and cost. Monteiro and Martins (2013) also claimed that quantity take-off process using BIM ensures easier, detailed, and accurate results for the project. Masood, Kharal and Nasir (2014) stated that BIM enables stakeholders to reach quantities in desired format and scale whenever required due to its automated process and by means of auto-quantification, it ensures accuracy, accountability, and value integration.

When there are irregular and complex items in the project, BIM ensures limited errors caused by computational operations due to its automated processes. Automated processes not only assure reduction in time spent on quantity take-off process but also create extra time for pricing process and decreases incompatibility between design output and measurement (Olatunji et al., 2010).

Despite the advantageous aspects of BIM based quantity take-off processes, there are also some limitations originated from difficulties in fully integrating BIM into project processes. Studies in the literature showed that it is not possible to obtain all required quantities from 3D models for a complete QTO process. There are still problems about obtaining accurate quantities of such construction items such as formwork and there is an insufficiency of BIM programs regarding manipulation of data to attain necessary quantities. Olatunji et al. (2010) stated that although BIM pledges remarkable advance for quantification process due to better cooperation and integration, there are also limitations arises from divergence between automated measurement feature of programs and general estimation traditions which is a result of insufficient adoption of BIM technology. Monteiro and Martins (2013) also stated that BIM models still not able to satisfy the requirements of users and not able to provide all expected data due to insufficiency of adaptation of BIM tools for different design conditions.

Consequently, BIM based quantity take-off process needs to be evaluated in terms of its limitations and accuracy of the outputs.

2.6. Comparison of Quantity Take-off Obtained Using CAD and BIM Tools

The main difference between CAD and BIM based quantity take-off processes is ensuring participation of the stakeholders. Unlike CAD based process, BIM based quantity take-off stimulates project's stakeholders to involve in the process, increase coordination between them and make participants to contribute to each phase of the lifecycle. Azhar et al. (2008) showed the difference between old (CAD) and new (BIM) processes with the Figure 2.3 below and explained that BIM encourages participants of the project, ensures harmony among them and by this way generate sufficient processes.

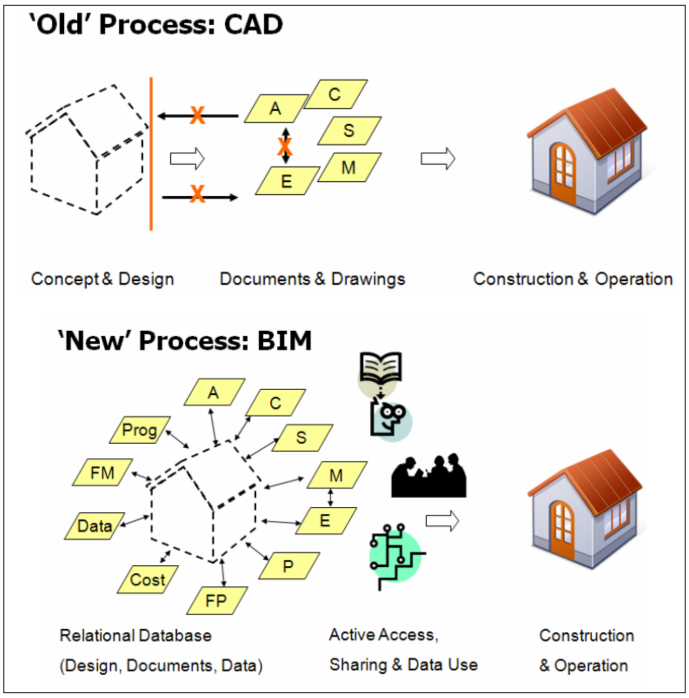


Figure 2.3. Comparison between Conventional CAD and New BIM Approach (Azhar et al., 2008)

BIM based quantity take-off process ensures automated systems. When the model is completed, table of quantities can be formed automatically and the result of each revision or correction can be achieved only by refreshing the tables. However, in CAD based quantity take-off systems, tables have to be created manually and when there are revisions or corrections, it is very difficult and time-consuming task to revise the tables. Amiri (2012) mentioned that one of the main benefit of BIM based process is when a revision in a project is actualized, update in the quantity take-off lists and also cost estimation can be done immediately. Olatunji et al. (2010) also stated that "automated measurement of quantities contained in BIM models, simultaneous access to design database, improved framework for communication between project teams, project visualization and simulation" are the beneficial features of BIM for the cost estimation processes.

When compared in terms of accuracy of outputs, studies showed that BIM based quantity take-off systems bring out more accurate results. One of the main reason is that BIM enhance coordination between different disciplines and by this way prevents clashes of items. One of the other reasons is that in BIM based process, it is easy to realize missing parts of model due to visualization features and therefore it minimizes omissions. One another reason is that BIM based process extinguish calculation errors originated from human error since the calculations are made automatically by the program. Azhar (2011) stated that according to the study conducted in Stanford University's Center for Integrated Facilities Engineering (CIFE) regarding 32 major projects that used BIM, the accuracy of cost estimation is within %3 when compared to CAD based quantity take-off process. Monteiro and Martins (2013) mentioned that CAD based quantity take-off processes cause some troubles in detecting clashes or omissions and determination of cascading issues. As a result, these problems directly affects the process and reduces the accuracy of the results. Sattineni and Bradford II (2011) asserted that BIM provides opportunity to finish cost estimation process in a shorter time with more accurate results.

BIM based quantity take-off process also have some disadvantages. Olsen and Taylor (2017) mentioned that BIM based quantity take-off process have two disadvantages; one of them is the time used for the creation of the model at the beginning of the process and the other one is the difficulty in usage of the software programs. On the contrary, CAD based quantity take-off process is the commonly used one and construction sector has a lot of experience on it. One of the other disadvantages of BIM based process is the insufficiency of data manipulation in the BIM tools. In order to manipulate the data, other software tools have to be used (Monteiro & Martins, 2013). There are still limitations for obtaining accurate quantities of some construction items such as formwork and it is not preferable to model some construction items such as rebar since there are easier options to get quantities with different programs and methods. Some of the important data about wastage, lapping etc. may be missing in the model since there is an inadequacy for the adoption of BIM for such kind of conditions.

In conclusion, although BIM based quantity take-off process has some limitations, it is obvious that it has various advantages when compared with the CAD based quantity take-off process.

2.7. Previous Studies on BIM based QTO

BIM usage and BIM based QTO are subjects of interest to previous researchers. Several notable studies relevant to this study are discussed in this section. Sattineni and Bradford II (2011) stated that there are two main challenges in the application of Building Information Modeling, which are the need for cultural change in the company and the reliance on the automated results obtained from a new program. Due to the difficulty in trusting the QTO values obtained from a BIM tool and lack of research studies to evaluate the BIM based QTO results, there is a resistance in switching to model based estimating processes in construction companies.

Bečvarovská and Matějka (2014) conducted a research in order to compare the BIM based and CAD based quantity take-off processes in terms of time and accuracy. For this reason, a single apartment building was chosen and have been modeled in Revit 2014 program. Quantities estimated manually and obtained from the model were compared. The differences between the acquired data were examined and reasons of deviations were established. The reasons of deviations can be grouped in 3 categories which are estimator errors (lack of deductions), design mistakes (wrong joints, inaccurate layers) and limitations of software (lack of tool for formwork and surface adjustment, insufficient tool for ground modeling). According to Bečvarovská and Matějka (2014), although there are differences arising from the BIM based method, the deviations are negligible and when compared in time, the BIM based method is 80% faster than the CAD based method. As a result, according to the study, BIM based quantity take-off process is advantageous for the considered project in terms of time and accuracy.

Khosakitchalert et al. (2018) performed a study with Autodesk Revit 2018 program to investigate the accuracy of architectural walls' quantity take-off. The study reveals that when there is an overlap between architectural walls and structural elements, although the graphic shows the wall as being cropped, deduction of wall area has not been done. In order to solve the problem, designers have to use join geometry tool for creating a cut between walls and structural elements. This tool ensures reaching the correct quantities for walls but it is obvious that it takes too much time for editing each joint and it is impractical. Besides, since the walls have been cut with structural elements, the areas of finish layers covering the structural elements are missing.

The results of the study can be seen in Figure 2.4. Figure 2.4 (A) shows the wall material area when the wall is outside the column. Figure 2.4 (B) shows the wall material area when drawing the wall through the column. Figure 2.4 (C) shows the wall material area decreased after using the Join Geometry tool. The red line shows the areas of the finish layers that are missing from the model.

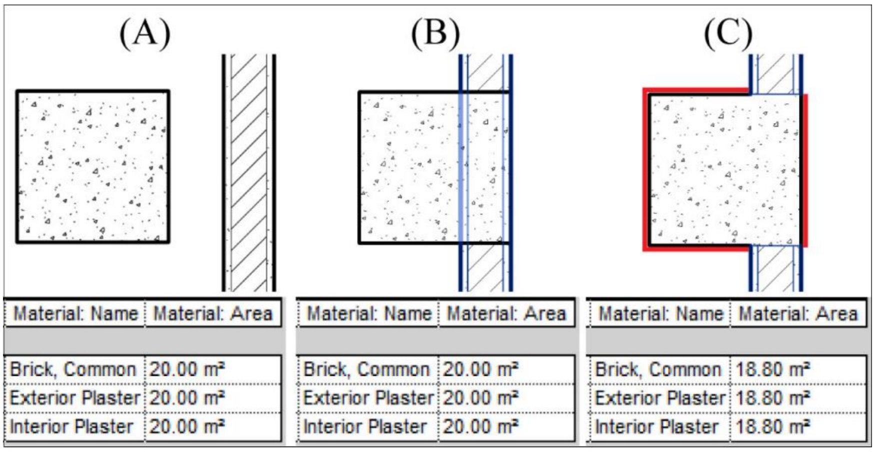


Figure 2.4. Comparison of Walls Quantity Take-off in Different Situations (Khosakitchalert et al., 2018)

Khosakitchalert et al. (2018) proposed a method to prevent the mistakes originated from insufficiency of the investigated program. A dynamo extension, which can be used to create an algorithm to manipulate the data obtained from the model, was used so as to reach the correct outputs. For each scenario, a different script was created and by this way, desired quantities can be achieved separately. Although accurate results are obtained by using Dynamo scripts, there are also some limitations. To illustrate, when there are multiple materials used in the surface, scripts cannot calculate the surface area correctly.

Bryde et al. (2013) conducted a research by collecting data from 35 different construction projects which used BIM. The data were gathered from case studies in academic journals and public domain collected via world-wide-web. Projects were examined in terms of 9 success criteria. According to the study, the most seen success criterion originated from BIM is the “cost reduction and control”. In 60 % of projects (21 of 35 projects), positive effects on cost were specified. The reasons of cost reduction are saving on project cost, removal of change orders due to prevention of field conflict, minimizing staff of project. In 5.71% of projects (2/35 projects), negative effects on cost were remarked. The reasons of cost increase are CAD rework cost, technological costs (upgrade, technical support), and educational costs (training of staff).

2.7.1. Gap in Literature

In construction industry, BIM is generally used for visualization and coordination of projects. Recently, other usage areas of BIM such as cost estimation, scheduling, documentation, safety, energy efficiency, facility management are put on the agenda of construction sector. There are studies regarding the effects of BIM on construction projects for these areas, however, only a few of them examines the effects of BIM implementation in terms of cost estimation.

Studies regarding the effects of BIM usage in total cost of construction projects generally semtinize the impacts of improved coordination, avoided clashes as well as prevented omissions and errors on cost. The studies about the accuracy of obtained quantities from BIM models commonly concentrate on acquiring quantities of construction items in standard situations. There is not sufficient number of studies investigating the problems in obtaining quantities of certain construction items such as formwork from BIM model and suggesting specific solutions required for particular design conditions such as inclined beams/columns, low floors, difference in the alignment of materials on facade. Besides, there is not enough research on the comparison of quantities obtained from different BIM tools and the reasons of these variations. Therefore, it is seen that there is a gap in the literature for examination of the accuracy of obtained quantity take-offs for different design conditions and there is a need for evaluation of the reliability of BIM based quantity take-off processes.

CHAPTER 3

CASE STUDY – MODELING WITH REVIT

3.1. Project Overview and Available Data

In this study, the Oral and Dental Health Center building which is a part of Elazığ Integrated Health Campus Project is selected to be modeled with Revit 2017 program in order to obtain and investigate model based QTO data. Gross building area (GBA) of the building is 13.048 m^2 and the building has 5 floors which are basement, ground floor, and upper 3 floors. The building has been constructed in 700 days and brought into service in 02.09.2018.

General information about the structure and the materials of the building is as follows:

Structure Type: Reinforced concrete building

Foundation Type: Strip foundation (a small area is raft foundation)

Exterior Wall Material: Cellular concrete

Facade Insulation Material: Rockwool

Exterior Window Materials: Aluminum frames and glass.

Interior Walls Materials: Cellular concrete and gypsum board

Doors: Metal doors, fire doors and wooden doors

Floor Covering Materials: Ceramic tile, mosaic tile, pvc, carpet and parquet

Ceilings Materials: Gypsum board, rockwool, and metal

At the beginning of the study, all necessary design drawings such as formwork plans, foundation plans, floor plans, wall plans, ceiling plans, facade plans were obtained from the design department. These drawings were taken into consideration during the modeling of the building with Autodesk Revit program. Last revision date of the drawings are also given in Table 3.1.

Table 3.1. *Last Revision Date of the Drawings*

Drawing Name	**Version Date**
Formwork Plans (Foundation)	5.04.2016
Formwork Plans (Building)	5.04.2016
Floor Plans	23.01.2018
Wall Plans	29.11.2017
Wall System Detail Plans	23.01.2018
Windows System Detail Plans	9.01.2017
Facade Plans	16.12.2016

The building was already modeled with Allplan program by the BIM department of the construction company and the quantities obtained from the model were used in the project processes such as preparation of the progress payments, the schedule, and the budget. There are some work items which are also not modeled with Allplan. These work items are excavation, leveling, backfilling, infrastructure, steel rebar, steel structures, facade scaffolding and fittings (mops and bins). Quantities of the modeled items with Allplan were provided by the company in order to enable comparison with the quantities obtained from Revit model. Estimated cost of the project was also acquired so as to evaluate how much of the project is modeled with Revit.

3.2. Modeled Construction Items

Only civil work are taken into account for this study, electrical and mechanical work are considered as out of scope. Since too much time is required to model all civil work items, firstly, the items which will be modeled within the scope of this study are decided. These items are foundation elements, structural elements (columns, beams, floors, structural walls, and parapet walls), vertical and horizontal beams in facade, exterior walls, curtain walls, facade insulation, exterior coating, exterior windows and doors. The number of modeled elements in Revit can be seen in Table 3.2. In order to apprehend the ratio of to be modeled work items' cost to building's total cost, a study was carried out by using estimated cost of the project. Work items were arranged and grouped and the ratios of each item's cost to the building's cost were calculated. Table 3.3 shows a detailed list of work items including information regarding their ratios to total, civil, and modeled costs, and their modeling status and scope status. The summary of this list has also been given in the tables available in section 1.5.3.

Table 3.2. *Number of Modeled Construction Items*

Construction Items	Number of Modeled Items
Foundation	152
Column	393
Structural Wall	28
Structural Beam	814
Floor	391
Parapet Wall	96
Vertical Beam	124
Horizontal Beam	531
Exterior Wall with Coating	1194
Insulation with Coating	1323
Exterior Windows and Curtain Walls	222
Exterior Doors	36

Excavation work, leveling, backfilling, facade scaffolding and fittings (mops and bins) were decided as out of scope and not modeled. Excavation, leveling, and backfilling work items are subjects of earthworks and it is better to estimate these work items with other drawing programs such as Netcad etc. Facade scaffolding is not a part of the building therefore it is decided to be considered apart from this study. Bins and mops are movable furniture and not fixed elements of the building, therefore it is decided to be considered as out of scope. Besides, these work items were not modeled with Allplan program either, hence there is no data to compare with even if they were modeled with Revit.

Interior work is not modeled since there are lots of work items whose cost only covers 27.06% of building's cost in the modeling scope as shown in Table 3.3. Hence, the time required for modeling these items does not add up to total cost of the building. Therefore, these items were not modeled in the scope of this study.

Table 3.3. *Ratio of Modeled Construction Item's Cost to Building's Cost*

COST CODE	WORK ITEM	ACCORDING TO BUILDING'S ENTIRE COST (CIVIL & ELC & MECH)		ACCORDING TO BUILDING'S CIVIL COST		ACCORDING TO BUILDING'S CIVIL COST (IN MODELING SCOPE)		SCOPE STATUS	MODELING STATUS
		RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS		
	TOTAL	**100.00%**	**12.07%**	**100.00%**	**28.60%**	**100.00%**	**30.05%**		
	EARTHWORKS AND INSULATION	**2.59%**	**0.00%**	**6.13%**	**0.00%**	**2.53%**	**0.00%**		
01010100	Excavation	1.35%	0.00%	3.21%	0.00%	0.00%	0.00%	Out of Scope	Not Modeled
01010130	Levelling	0.01%	0.00%	0.02%	0.00%	0.00%	0.00%	Out of Scope	Not Modeled
01010210	Backfilling	0.20%	0.00%	0.48%	0.00%	0.00%	0.00%	Out of Scope	Not Modeled
01040210	Lean Concrete (h:10 cm)	0.29%	0.00%	0.70%	0.00%	0.73%	0.00%	In the Scope	Not Modeled
01040230	Waterproofing - Foundation	0.17%	0.00%	0.40%	0.00%	0.42%	0.00%	In the Scope	Not Modeled
01040240	Geotextile felt - Foundation	0.01%	0.00%	0.03%	0.00%	0.04%	0.00%	In the Scope	Not Modeled
01040260	Protective Concrete (h:10 cm)	0.18%	0.00%	0.42%	0.00%	0.44%	0.00%	In the Scope	Not Modeled
01040310	Bituminous Primer - Structural Wall	0.01%	0.00%	0.02%	0.00%	0.02%	0.00%	In the Scope	Not Modeled
01040320	Waterproofing - Structural Wall	0.16%	0.00%	0.37%	0.00%	0.39%	0.00%	In the Scope	Not Modeled
01040330	Thermal Insulation with XPS - Structural Wall	0.16%	0.00%	0.37%	0.00%	0.39%	0.00%	In the Scope	Not Modeled
01040340	Geocomposite Protective Plate - Structural Wall	0.04%	0.00%	0.11%	0.00%	0.11%	0.00%	In the Scope	Not Modeled
	MAIN STRUCTURE WORK	**20.21%**	**7.94%**	**47.88%**	**18.80%**	**50.32%**	**19.76%**		
02010311	Formwork - Foundation	0.15%	0.15%	0.35%	0.35%	0.37%	0.37%	In the Scope	**Modeled**
02010313	Steel rebar - Fondation	2.82%	0.00%	6.68%	0.00%	7.02%	0.00%	In the Scope	Not Modeled
02010315	Concrete - Foundation	1.18%	1.18%	2.80%	2.80%	2.94%	2.94%	In the Scope	**Modeled**
02030111	Formwork - Column	0.47%	0.47%	1.11%	1.11%	1.17%	1.17%	In the Scope	**Modeled**
02030113	Steel rebar - Column	0.87%	0.00%	2.06%	0.00%	2.17%	0.00%	In the Scope	Not Modeled

Table 3.3. *Ratio of Modeled Construction Item's Cost to Building's Cost*

COST CODE	WORK ITEM	ACCORDING TO BUILDING'S ENTIRE COST (CIVIL & ELC & MECH)		ACCORDING TO BUILDING'S CIVIL COST		ACCORDING TO BUILDING'S CIVIL COST (IN MODELING SCOPE)		SCOPE STATUS	MODELING STATUS
		RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS		
02030115	Concrete - Column	0.28%	0.28%	0.67%	0.67%	0.71%	0.71%	In the Scope	**Modeled**
02030111	Formwork - Beam	0.81%	0.81%	1.92%	1.92%	2.02%	2.02%	In the Scope	**Modeled**
02030113	Steel rebar - Beam	2.17%	0.00%	5.14%	0.00%	5.40%	0.00%	In the Scope	Not Modeled
02030115	Concrete - Beam	0.71%	0.71%	1.67%	1.67%	1.76%	1.76%	In the Scope	**Modeled**
02030111	Formwork - Floor	1.38%	1.38%	3.26%	3.26%	3.43%	3.43%	In the Scope	**Modeled**
02030113	Steel rebar - Floor	3.20%	0.00%	7.57%	0.00%	7.96%	0.00%	In the Scope	Not Modeled
02030115	Concrete - Floor	1.04%	1.04%	2.46%	2.46%	2.59%	2.59%	In the Scope	**Modeled**
02030111	Formwork - Structural Wall	0.86%	0.86%	2.04%	2.04%	2.14%	2.14%	In the Scope	**Modeled**
02030113	Steel rebar - Structural Wall	2.49%	0.00%	5.89%	0.00%	6.19%	0.00%	In the Scope	Not Modeled
02030115	Concrete - Structural Wall	0.81%	0.81%	1.91%	1.91%	2.01%	2.01%	In the Scope	**Modeled**
02030111	Formwork - Parapet Wall	0.18%	0.18%	0.42%	0.42%	0.44%	0.44%	In the Scope	**Modeled**
02030113	Steel rebar - Parapet Wall	0.24%	0.00%	0.57%	0.00%	0.60%	0.00%	In the Scope	Not Modeled
02030115	Concrete - Parapet Wall	0.08%	0.08%	0.19%	0.19%	0.19%	0.19%	In the Scope	**Modeled**
02090120	Steel Works	0.49%	0.00%	1.16%	0.00%	1.22%	0.00%	In the Scope	Not Modeled
	WALL WORK	**6.64%**	**0.89%**	**15.73%**	**2.11%**	**16.53%**	**2.21%**		
03010130	Exterior wall (Gas Concrete) w: 15cm	0.00%	0.00%	0.01%	0.01%	0.01%	0.01%	In the Scope	**Modeled**
03010130	Exterior wall (Gas Concrete) w: 28cm	0.25%	0.25%	0.59%	0.59%	0.62%	0.62%	In the Scope	**Modeled**
03010211	Exterior wall horizontal beam	0.16%	0.16%	0.37%	0.37%	0.39%	0.39%	In the Scope	**Modeled**
03010211	Exterior wall vertical beam	0.48%	0.48%	1.13%	1.13%	1.19%	1.19%	In the Scope	**Modeled**

Table 3.3. *Ratio of Modeled Construction Item's Cost to Building's Cost*

COST CODE	WORK ITEM	ACCORDING TO BUILDING'S ENTIRE COST (CIVIL & ELC & MECH)		ACCORDING TO BUILDING'S CIVIL COST		ACCORDING TO BUILDING'S CIVIL COST (IN MODELING SCOPE)		SCOPE STATUS	MODELING STATUS
		RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS		
03020130	Interior wall (Gas Concrete) w: 15cm	0.38%	0.00%	0.90%	0.00%	0.95%	0.00%	In the Scope	Not Modeled
03020130	Interior wall (Gas Concrete) w: 25cm	0.01%	0.00%	0.02%	0.00%	0.03%	0.00%	In the Scope	Not Modeled
03020211	Interior wall horizontal beam (lintel)	0.09%	0.00%	0.22%	0.00%	0.23%	0.00%	In the Scope	Not Modeled
03020211	Interior wall vertical beam	0.04%	0.00%	0.10%	0.00%	0.11%	0.00%	In the Scope	Not Modeled
03020160	Interior wall (Gypsum Board) - Type 1	1.36%	0.00%	3.22%	0.00%	3.38%	0.00%	In the Scope	Not Modeled
03020160	Interior wall (Gypsum Board) - Type 2	0.84%	0.00%	1.98%	0.00%	2.08%	0.00%	In the Scope	Not Modeled
03030210	Cement Plaster Wall Covering - Interior	0.35%	0.00%	0.83%	0.00%	0.87%	0.00%	In the Scope	Not Modeled
06010210	Gypsum Plaster Wall Covering - Interior	0.52%	0.00%	1.24%	0.00%	1.30%	0.00%	In the Scope	Not Modeled
06010211	Satin Plaster Wall Covering - Interior	0.32%	0.00%	0.76%	0.00%	0.79%	0.00%	In the Scope	Not Modeled
06010314	Ceramic Tile Wall Covering - Interior	0.27%	0.00%	0.65%	0.00%	0.68%	0.00%	In the Scope	Not Modeled
06010327	Lead Plate Wall Covering - Interior	0.08%	0.00%	0.20%	0.00%	0.21%	0.00%	In the Scope	Not Modeled
06010328	PVC Plate Wall Covering - Interior	0.09%	0.00%	0.22%	0.00%	0.23%	0.00%	In the Scope	Not Modeled
06010410	Wallpaper Covering - Interior	0.01%	0.00%	0.01%	0.00%	0.01%	0.00%	In the Scope	Not Modeled
06010520	Interior Wall Painting	0.46%	0.00%	1.09%	0.00%	1.15%	0.00%	In the Scope	Not Modeled
05020311	Interior Glazing	0.35%	0.00%	0.83%	0.00%	0.87%	0.00%	In the Scope	Not Modeled
06030120	Metal Guard-Rail - Interior	0.14%	0.00%	0.34%	0.00%	0.36%	0.00%	In the Scope	Not Modeled
06030140	Glass Guard-Rail - Interior	0.43%	0.00%	1.01%	0.00%	1.06%	0.00%	In the Scope	Not Modeled
	FLOOR WORK	**3.44%**	**0.00%**	**8.14%**	**0.00%**	**8.55%**	**0.00%**		
03040120	Screed (h:7cm)	0.62%	0.00%	1.47%	0.00%	1.54%	0.00%	In the Scope	Not Modeled

Table 3.3. *Ratio of Modeled Construction Item's Cost to Building's Cost*

COST CODE	WORK ITEM	ACCORDING TO BUILDING'S ENTIRE COST (CIVIL & ELC & MECH)		ACCORDING TO BUILDING'S CIVIL COST		ACCORDING TO BUILDING'S CIVIL COST (IN MODELING SCOPE)		SCOPE STATUS	MODELING STATUS
		RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS		
06020210	Ceramic Tile Floor Covering	0.46%	0.00%	1.09%	0.00%	1.14%	0.00%	In the Scope	Not Modeled
06020210	Ceramic Granite Floor Covering	0.21%	0.00%	0.49%	0.00%	0.51%	0.00%	In the Scope	Not Modeled
06020212	Natural Stone Floor Covering	0.11%	0.00%	0.26%	0.00%	0.27%	0.00%	In the Scope	Not Modeled
06020232	Laminated parquet Floor Covering	0.04%	0.00%	0.09%	0.00%	0.09%	0.00%	In the Scope	Not Modeled
06020235	Tile Floor Covering	0.34%	0.00%	0.82%	0.00%	0.86%	0.00%	In the Scope	Not Modeled
06020241	Carpet Covering	0.10%	0.00%	0.24%	0.00%	0.25%	0.00%	In the Scope	Not Modeled
06020250	PVC Floor Covering	0.74%	0.00%	1.75%	0.00%	1.84%	0.00%	In the Scope	Not Modeled
06020510	Raised Floor	0.52%	0.00%	1.23%	0.00%	1.29%	0.00%	In the Scope	Not Modeled
06030314	Tile Stair Covering	0.30%	0.00%	0.72%	0.00%	0.75%	0.00%	In the Scope	Not Modeled
	CEILING WORK	**1.68%**	**0.00%**	**3.99%**	**0.00%**	**4.19%**	**0.00%**		
06040130	Gypsum Suspended Ceiling	0.60%	0.00%	1.43%	0.00%	1.50%	0.00%	In the Scope	Not Modeled
06040130	Acoustics Gypsum Suspended Ceiling	0.12%	0.00%	0.28%	0.00%	0.29%	0.00%	In the Scope	Not Modeled
06040140	Metal Suspended Ceiling	0.05%	0.00%	0.11%	0.00%	0.11%	0.00%	In the Scope	Not Modeled
06040230	Rockwool Suspended Ceiling	0.53%	0.00%	1.25%	0.00%	1.32%	0.00%	In the Scope	Not Modeled
06040420	Gypsum Plaster Ceiling Covering	0.05%	0.00%	0.12%	0.00%	0.12%	0.00%	In the Scope	Not Modeled
06040422	Satin Plaster Ceiling Covering	0.16%	0.00%	0.37%	0.00%	0.39%	0.00%	In the Scope	Not Modeled
06040520	Ceiling Painting	0.18%	0.00%	0.43%	0.00%	0.46%	0.00%	In the Scope	Not Modeled
	ROOF WORK	**1.32%**	**0.00%**	**3.12%**	**0.00%**	**3.28%**	**0.00%**		
04010140	Thermal Insulation with XPS (10cm)	0.30%	0.00%	0.72%	0.00%	0.76%	0.00%	In the Scope	Not Modeled

Table 3.3. *Ratio of Modeled Construction Item's Cost to Building's Cost*

COST CODE	WORK ITEM	ACCORDING TO BUILDING'S ENTIRE COST (CIVIL & ELC & MECH)		ACCORDING TO BUILDING'S CIVIL COST		ACCORDING TO BUILDING'S CIVIL COST (IN MODELING SCOPE)		SCOPE STATUS	MODELING STATUS
		RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS		
04010155	Slope Concrete	0.27%	0.00%	0.65%	0.00%	0.68%	0.00%	In the Scope	Not Modeled
04010160	Waterproofing - Terrace	0.29%	0.00%	0.70%	0.00%	0.73%	0.00%	In the Scope	Not Modeled
04010160	Geotextile felt	0.01%	0.00%	0.03%	0.00%	0.03%	0.00%	In the Scope	Not Modeled
04010160	Waterproofing - Parapet	0.07%	0.00%	0.18%	0.00%	0.19%	0.00%	In the Scope	Not Modeled
04010270	Aluminum Coping	0.36%	0.00%	0.85%	0.00%	0.90%	0.00%	In the Scope	Not Modeled
	FACADE WORK	**2.71%**	**2.06%**	**6.41%**	**4.87%**	**5.77%**	**5.12%**		
04020131	Facade Thermal Insulation (Rockwool)	0.57%	0.57%	1.34%	1.34%	1.41%	1.41%	In the Scope	**Modeled**
03030111	Facade Cement Plastering	0.38%	0.38%	0.89%	0.89%	0.93%	0.93%	In the Scope	**Modeled**
03030111	Facade Mineral Plastering	0.17%	0.17%	0.41%	0.41%	0.44%	0.44%	In the Scope	**Modeled**
04020410	Painting - Exterior	0.17%	0.17%	0.41%	0.41%	0.44%	0.44%	In the Scope	**Modeled**
04020220	Aluminum Curtain Walls	0.68%	0.68%	1.62%	1.62%	1.70%	1.70%	In the Scope	**Modeled**
04020330	Aluminum Window ledge	0.26%	0.00%	0.62%	0.00%	0.65%	0.00%	In the Scope	Not Modeled
04020530	Aluminum Headwall	0.08%	0.08%	0.20%	0.20%	0.21%	0.21%	In the Scope	**Modeled**
04020610	Facade Scaffolding	0.39%	0.00%	0.92%	0.00%	0.00%	0.00%	Out of Scope	Not Modeled
	DOORS AND WINDOWS	**3.55%**	**1.19%**	**8.40%**	**2.82%**	**8.83%**	**2.96%**		
05010122	Fire Doors - Exterior	0.03%	0.03%	0.07%	0.07%	0.07%	0.07%	In the Scope	**Modeled**
05010125	Sliding Door - Exterior	0.03%	0.03%	0.07%	0.07%	0.07%	0.07%	In the Scope	**Modeled**
05010130	Metal Doors - Exterior	0.13%	0.13%	0.31%	0.31%	0.33%	0.33%	In the Scope	**Modeled**
05010220	Exterior Windows	1.00%	1.00%	2.37%	2.37%	2.50%	2.50%	In the Scope	**Modeled**

Table 3.3. *Ratio of Modeled Construction Item's Cost to Building's Cost*

COST CODE	WORK ITEM	ACCORDING TO BUILDING'S ENTIRE COST (CIVIL & ELC & MECH)		ACCORDING TO BUILDING'S CIVIL COST		ACCORDING TO BUILDING'S CIVIL COST (IN MODELING SCOPE)		SCOPE STATUS	MODELING STATUS
		RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS	RATIO OF ALL ITEMS	RATIO OF MODELED ITEMS		
05010260	Acrylic window ledge - Interior	0.20%	0.00%	0.46%	0.00%	0.49%	0.00%	In the Scope	Not Modeled
05020121	Wooden Door (Single wing) - Interior	0.82%	0.00%	1.94%	0.00%	2.04%	0.00%	In the Scope	Not Modeled
05020121	Wooden Door (Double wing) - Interior	0.02%	0.00%	0.06%	0.00%	0.06%	0.00%	In the Scope	Not Modeled
05020130	Hermetic Sliding Door - Interior	0.06%	0.00%	0.14%	0.00%	0.15%	0.00%	In the Scope	Not Modeled
05020130	Sliding Door - Interior	0.41%	0.00%	0.97%	0.00%	1.02%	0.00%	In the Scope	Not Modeled
05020132	Metal Doors (Single wing) - Interior	0.08%	0.00%	0.18%	0.00%	0.19%	0.00%	In the Scope	Not Modeled
05020132	Metal Doors (Double wing) - Interior	0.04%	0.00%	0.10%	0.00%	0.11%	0.00%	In the Scope	Not Modeled
05020136	Fire Doors (Single wing) - Interior	0.31%	0.00%	0.74%	0.00%	0.77%	0.00%	In the Scope	Not Modeled
05020136	Fire Doors (Double wing) - Interior	0.37%	0.00%	0.88%	0.00%	0.93%	0.00%	In the Scope	Not Modeled
05020160	Fire Shutter - Interior	0.05%	0.00%	0.12%	0.00%	0.12%	0.00%	In the Scope	Not Modeled
	FITTINGS	**0.08%**	**0.00%**	**0.20%**	**0.00%**	**0.00%**	**0.00%**		
12020510	Mops	0.06%	0.00%	0.13%	0.00%	0.00%	0.00%	Out of Scope	Not Modeled
12040310	Bins	0.03%	0.00%	0.07%	0.00%	0.00%	0.00%	Out of Scope	Not Modeled
	MECHANICAL WORK	**25.90%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	Out of Scope	Not Modeled
	ELECTRICAL WORK	**31.90%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	Out of Scope	Not Modeled

Foundation and other structural elements (columns, beams, floors etc.) were modeled in order to obtain formwork and concrete quantities. However, steel rebars were not modeled. There are two reasons for not modelling the steel rebars. First reason is that modeling steel rebars with Revit is a time-consuming and tedious task. There are programs for automatically extracting the quantities from 2D drawings easily and rapidly. Therefore, it is not convenient to model steel rebars in Revit. Second reason is that the steel rebars have not been modeled with Allplan either during the study carried out by the BIM department of the company and because of that there is not available data to compare the quantities of steel rebars.

When Table 3.3 is examined, it is seen that ratio of the modeled construction item's cost to building's entire cost is 12.07%. Since electrical and mechanical work are not considered in the scope of this study, 57.80% of building's cost is remained outside of the scope. Ratio of the modeled main structure work cost is 7.94%, ratio of the modeled wall work cost is 0.89%, ratio of the modeled facade work cost is 2.06% and ratio of the modeled doors and windows cost is 1.19%. When only the building's civil cost is considered, ratio of the modeled construction item's cost in building's entire civil costs is 28.60%, ratio of the modeled main structure work cost is 18.80%, ratio of the modeled wall work cost is 2.11%, ratio of the modeled facade work cost is 4.87% and ratio of the modeled doors and windows cost is 2.82%. In relation to building's civil cost considered in the modeling scope of this study, ratio of the modeled construction item's cost is 30.05%, ratio of the modeled main structure work cost is 19.76%, ratio of the modeled wall work cost is 2.21%, ratio of the modeled facade work cost is 5.12% and ratio of the modeled doors and windows cost is 2.96%.

Consequently, it can be noticed that only structural elements and elements in facade are modeled in the scope of this study. Interior work items, roof work items, foundation insulation work items are not modeled and the quantities of these items are not compared.

3.3. Modeling Methods

3.3.1. General Settings of Model

At the beginning of the study, general adjustments for the Revit model were carried out. Project unit was selected as “cm” to be compatible with the design drawings since almost all design drawings were created with a scale of 1/100. By this way, probable unit translation work during creation of the model was prevented. After that, floor heights were defined in the model and then grids and axes were formed.

3.3.2. Modeling of Foundation

Firstly, the foundation of the building was modeled. Foundation type of the project is strip foundation, only a small part of the foundation is raft foundation. In order to model a foundation, structural foundation slab feature of the program was used. A family for foundation slab was formed and the foundation beam types having different sizes were created. Material type was selected as concrete. The number of each foundation slab part written in project drawings were entered into model as well. Figure 3.1 shows the general view of foundation model. There are wall openings in some parts of the foundation walls but there is no way to create an opening on a structural slab foundation element in the model. Therefore, foundation walls having openings were created as structural walls. Figure 3.2 shows the example of a foundation wall having a wall opening which is created as a structural wall.

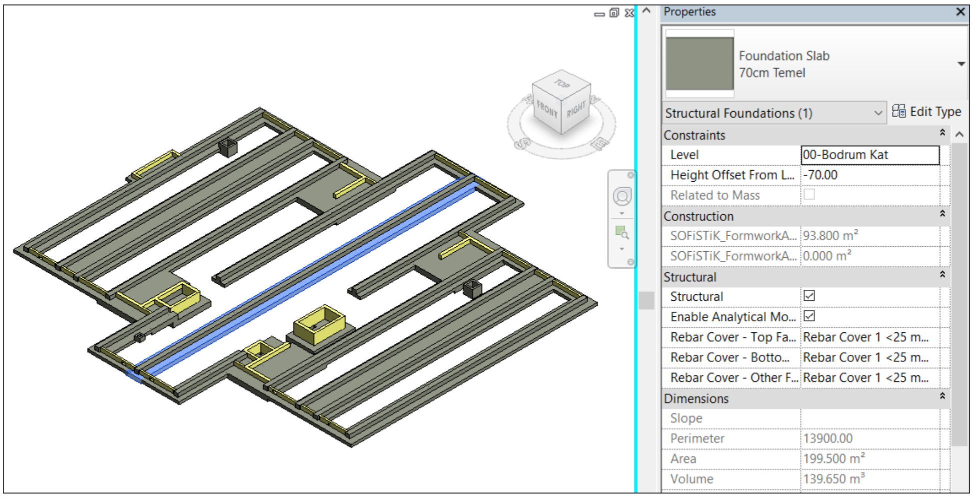


Figure 3.1. General view of Foundation

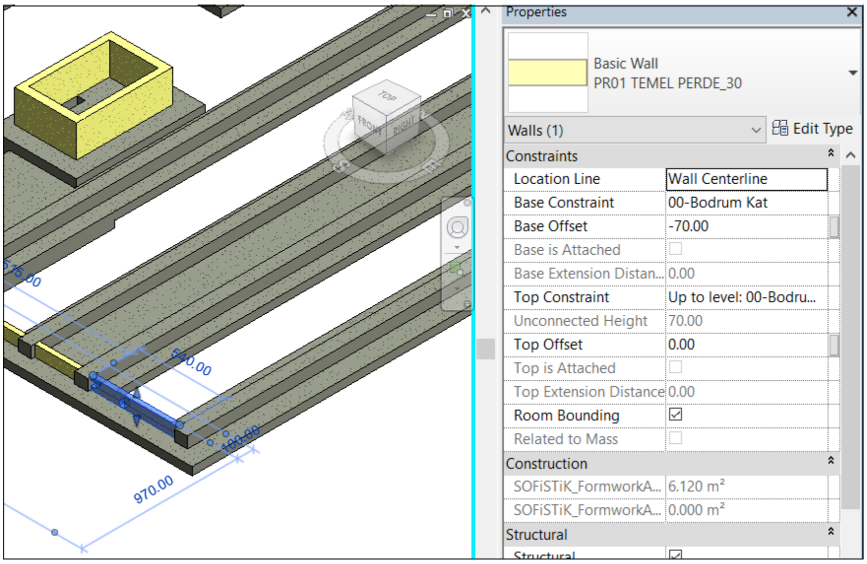


Figure 3.2. Vertical opening in Foundation Walls

3.3.3. Modeling of Columns

After foundation, the columns were modeled. Column family was formed and column types were created according to the sizes of the columns given in the project drawings. Material of columns was selected as concrete. The naming of columns are carried out according to the number of each column written in project drawings. Since there are low floors in the building, height of the columns are not same throughout the floors. Therefore, after modeling each column from floor to floor, the heights of the columns were checked and adjusted according to their actual heights. Figure 3.3 shows an example of the shorter columns due to the low floor.

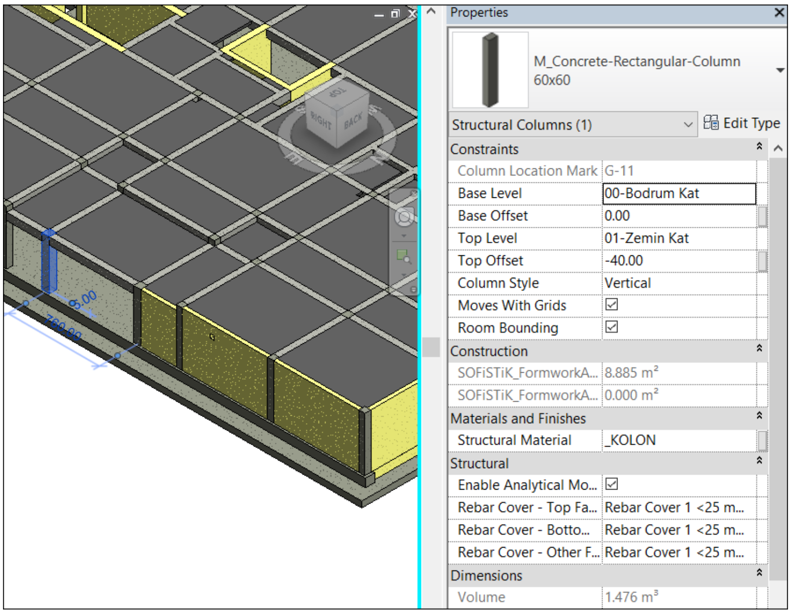


Figure 3.3. A Shorter Column due to Low Floor

3.3.4. Modeling of Structural Walls

Together with the columns, structural walls were also modeled. A wall family was formed for the structural walls and wall types were created according to the thicknesses of the structural walls. Material of structural walls was selected as concrete. The number of each structural wall written in project drawings were entered into the model. Like columns, some of the structural walls' heights are lower than the floor height due to low floors. Therefore, height of each structural wall was checked and adjusted according to its actual height in the project drawings. Figure 3.4 shows a shorter structural wall due to the low floor at that location.

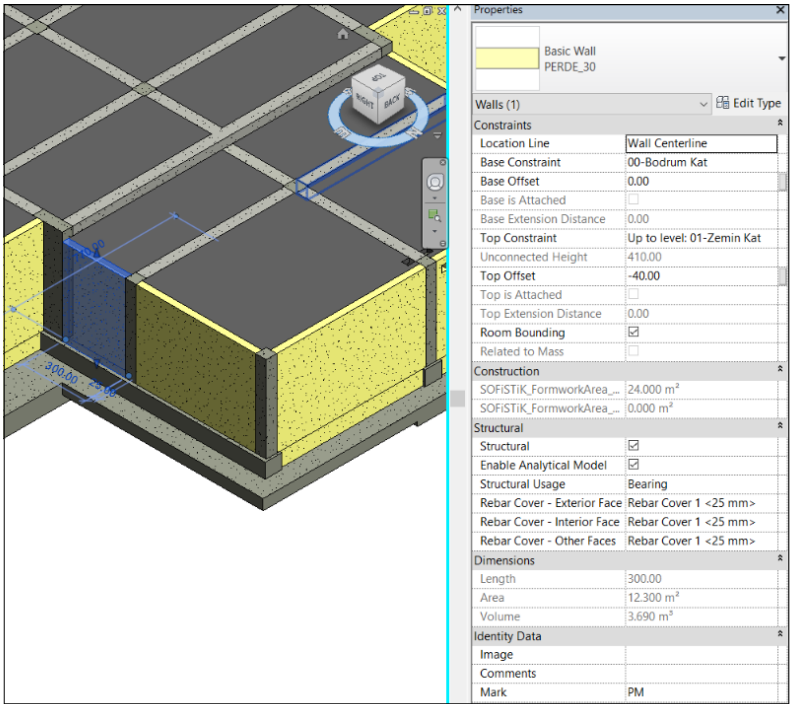


Figure 3.4. A Shorter Structural Wall due to Low Floor

3.3.5. Modeling of Beams

The beams were modeled from column to column or structural wall to structural wall. A beam family was formed and then beam types were created according to their sizes. Material of the beams was selected as concrete. The numbers of the beams in the model were given according to the project drawings. While modeling beams, it is better to draw a beam line from exterior side of the column to the other column or from exterior side of the structural wall to the other structural wall. When a beam is drawn from center of the column, a virtual beam inside of the column having no volume is created. This beam is listed in the quantity take-off table as an element, however, no calculated formwork area or volume for this element appears in the list. Therefore, quantity take-off is not affected but this situation may cause a confusion as additional beam elements will be listed in QTO. Figure 3.5 shows an example of this type of beams.

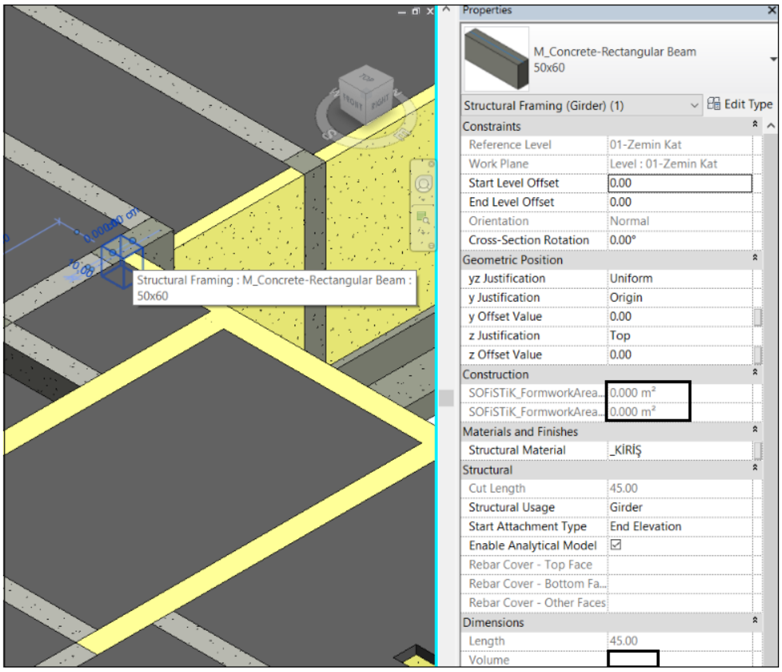


Figure 3.5. A Beam in Column Having No Volume and No Formwork Area

3.3.6. Modeling of Floors

The floors (slabs) were modeled between the area surrounded by columns, structural walls, and beams. A floor family was formed and floor types were created according to the thickness of the floors. Material of the floors was selected as concrete. The number of each floor were entered into model according to project drawings. Since there are low floors, levels of each floor were checked and required adjustments were carried out. The level of the floor is important because in order to obtain a consistent quantity take-off, the level of columns, structural walls and beams need to be adjusted according to the floor level. Figure 3.6 shows an example of a low floor where top level of the beams, columns and structural walls are at the same level as its bottom.

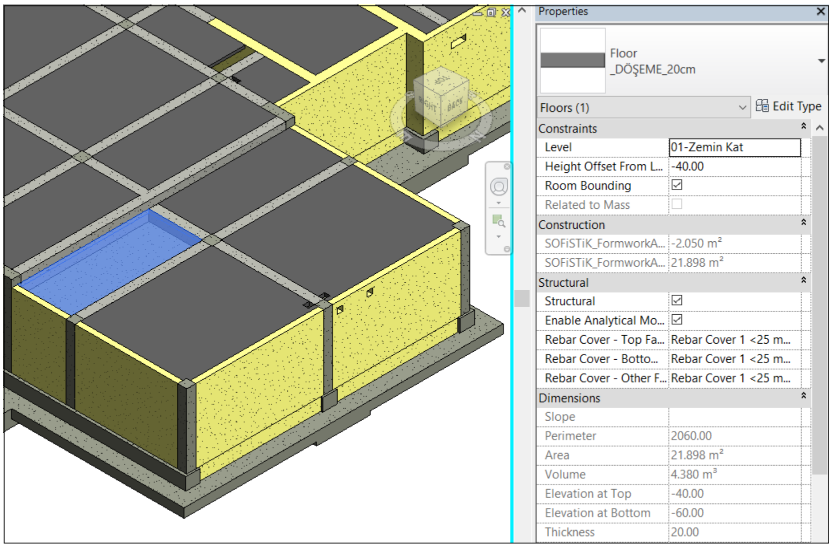


Figure 3.6. A Low Floor Example

3.3.7. Modeling Parapet Walls

In order to model the parapet walls, a structural wall family was formed and parapet walls were created according to the thickness of the walls. Material of the parapet walls was concrete. The number of parapet walls written in project drawings were entered into the model. Figure 3.7 shows an example of the parapet walls.

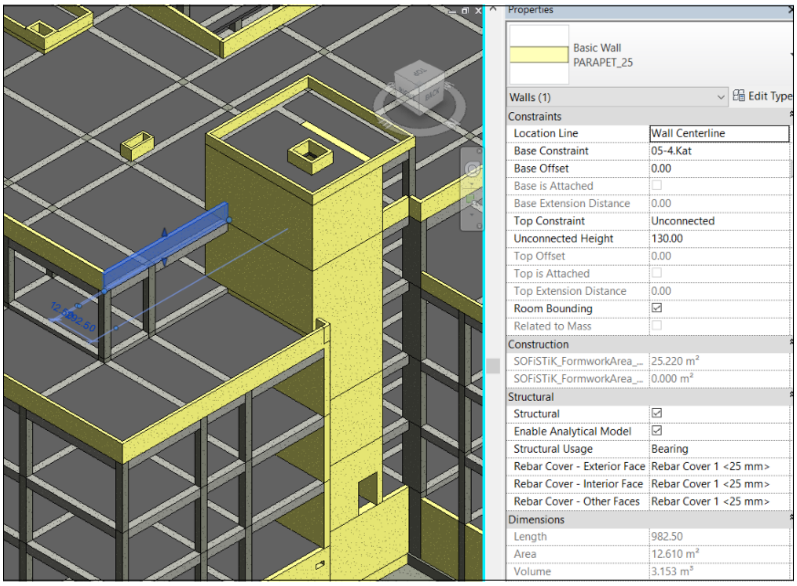


Figure 3.7. A Parapet Wall Example

3.3.8. Modeling of Vertical and Horizontal Beams

After modeling the structural framework of the building, vertical and horizontal beams which are necessary for durability of architectural walls were modeled. Vertical beams and horizontal beams were modeled respectively. Vertical beams were modeled with a structural column family, horizontal beams were modeled with a structural beam family. Horizontal and vertical beam types are created according to their sizes. Material of vertical and horizontal beams was selected as concrete. All vertical beams are located under structural beams, so the height of vertical beams were adjusted with regard to the bottom level of main beams. Figure 3.8 shows an example of vertical and horizontal beams.

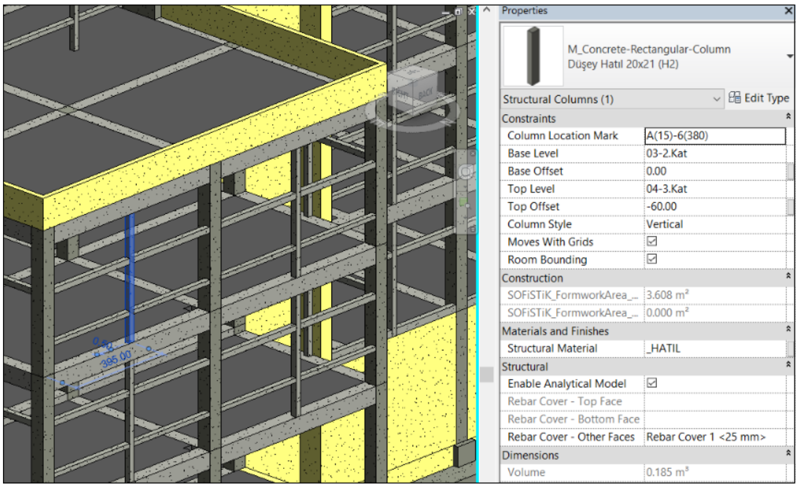


Figure 3.8. An Example of Vertical and Horizontal Beams

Actually, horizontal and vertical beams are constructed together with the architectural walls during the construction phase. When vertical and horizontal beams are modeled together with the architectural walls in Revit, join command needs to be used in order to deduct the surface area of beams from the architectural wall's area. Structural elements are not accepted as a dominating element in Revit and therefore surface area of beams are not deducted from architectural wall's area automatically. Figure 3.9 and 3.10 shows an example of architectural wall's area before and after applying the join feature. In this example, thickness of the wall and the beams are same and they are placed with the same vertical alignment. In Figure 3.9, the area of architectural wall was calculated as 22.23 m^2 since the join feature has not been used. After using the join feature, as seen in Figure 3.10, the area of architectural wall is reduced to 20.35 m^2 which is true as confirmed with manual calculations.

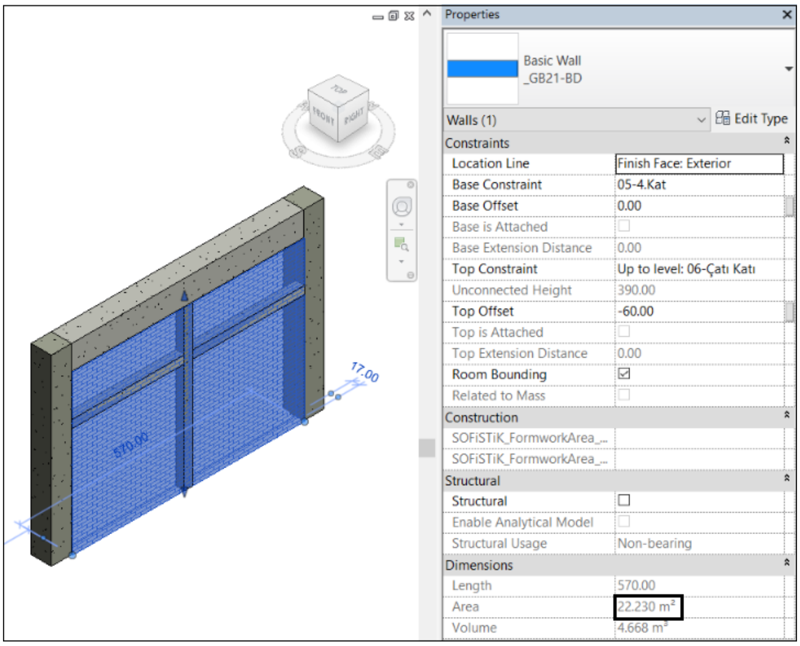


Figure 3.9. Area of an Architectural Wall (before Using Join Feature of Revit)

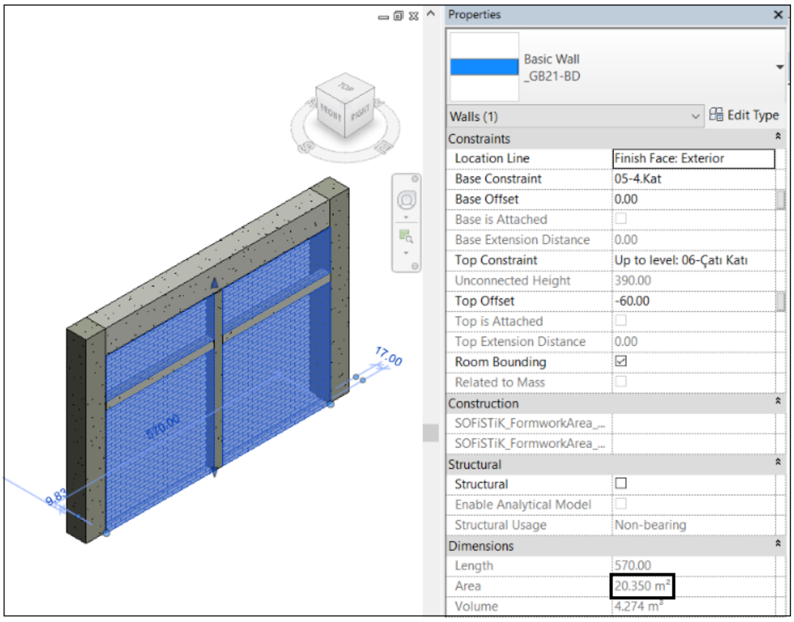


Figure 3.10. Area of an Architectural Wall (after Using Join Feature of Revit)

According to the facade design of the case study building, exterior walls are positioned as exterior faces being 7 cm outside of the structural framework. The thickness of vertical and horizontal beams are 21 cm and the thickness of exterior walls is 28 cm. Vertical and horizontal beams are also located at the same vertical alignment as structural framework. Since the outer surface of the walls are not aligned with outer surface of the vertical beams, the surface area of beams is not being reduced from architectural walls area in Revit model. Figure 3.11 and 3.12 shows an example of architectural wall's area before and after applying the join feature when such a design is encountered. In Figure 3.11, the area of the architectural wall is calculated as 22.23 m^2 before using the join feature and in Figure 3.12, the area of the architectural wall is again calculated as 22.23 m^2 after using the join feature. It is clearly seen that the results are same and results are not changed by using the join feature. Therefore, the correct quantity which is 20.35 m^2 cannot be obtained from Revit model when there is such kind of a situation.

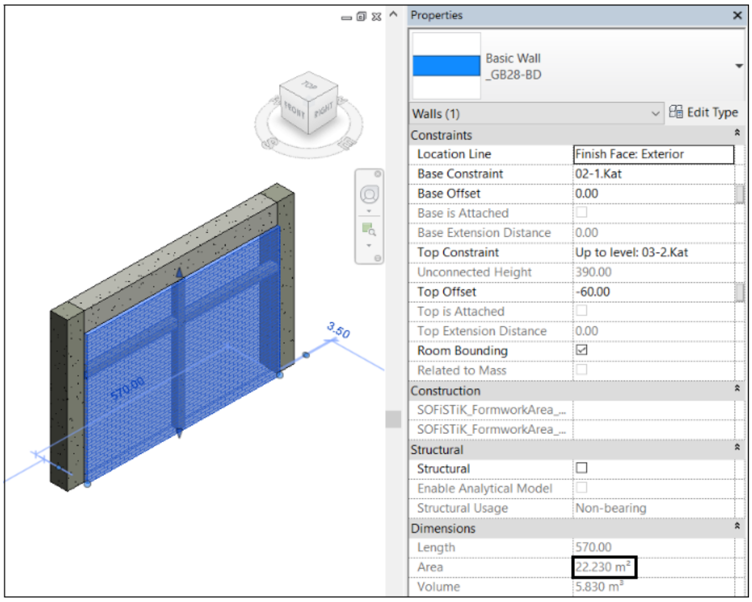


Figure 3.11. Area of an Architectural Wall (Exterior Face not Aligned with Structural Frame - before Using Join Feature of Revit)

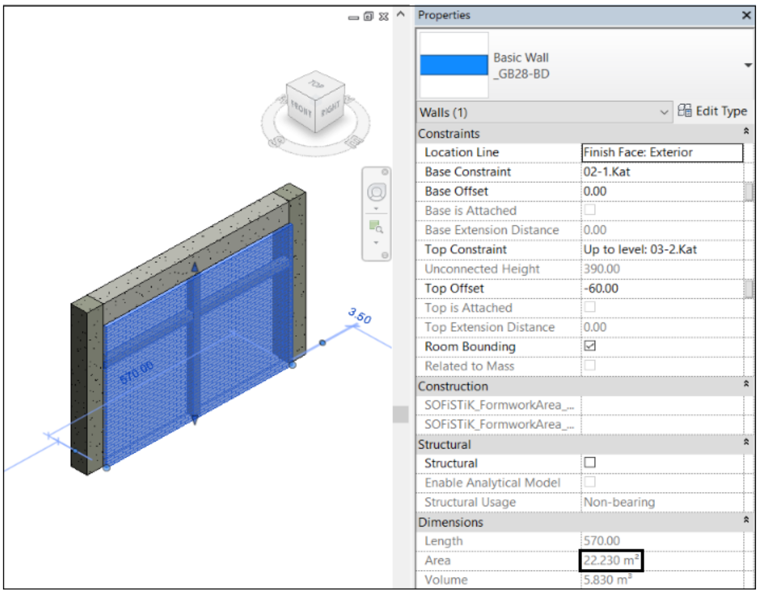


Figure 3.12. Area of an Architectural Wall (Exterior Face not Aligned with Structural Frame - after Using Join Feature of Revit)

Hence, in order to obtain an accurate quantity take-off from Revit in such kind of circumstances, it is better to model vertical and horizontal beams before the architectural walls and then architectural walls should be modeled between beams in parts. Figure 3.13 shows an example of the architectural wall modeled in pieces. In this figure, area of the selected wall is seen as a 7.425 m^2 and area of the other parts are 7.425 m^2, 2.75 m^2, and 2.75 m^2. When area of each piece are added up, it is seen that the total area of 20.35 m^2 can be correctly achieved.

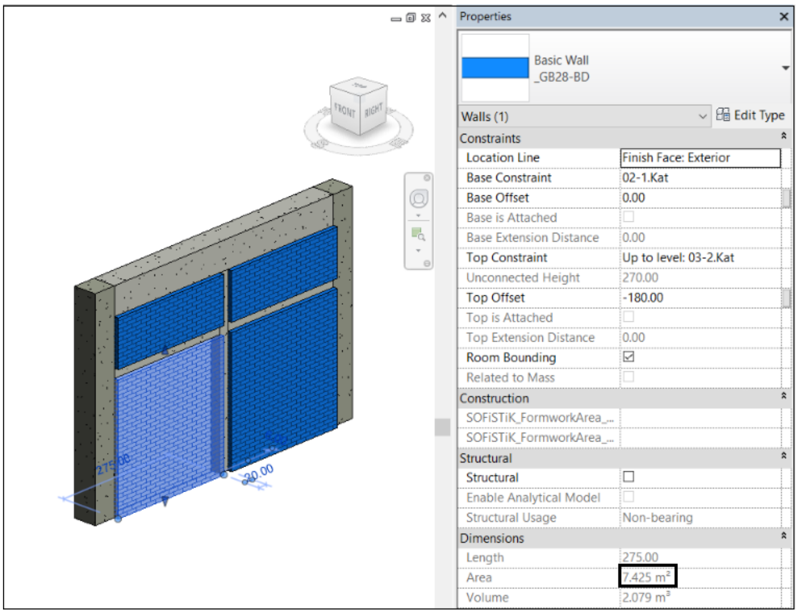


Figure 3.13. Architectural Wall Modeled in Pieces

3.3.9. Modeling of Exterior Walls with Coating

The exterior walls were modeled in parts according to the allocation of vertical and horizontal beams as mentioned before. An architectural wall family was formed and wall types were created according to the thickness and layers of the walls. Material of exterior walls was selected as cellular concrete. In Revit, layers can be created in both exterior and interior face of the walls. For exterior plastering and painting, layers were created and both plaster and paint were modeled together with the exterior walls as one component. Figure 3.14 shows an example of the wall having plaster and paint layers on exterior face. Like area of the architectural wall itself, area of the plastering and painting are also calculated by adding up the area of each wall piece.

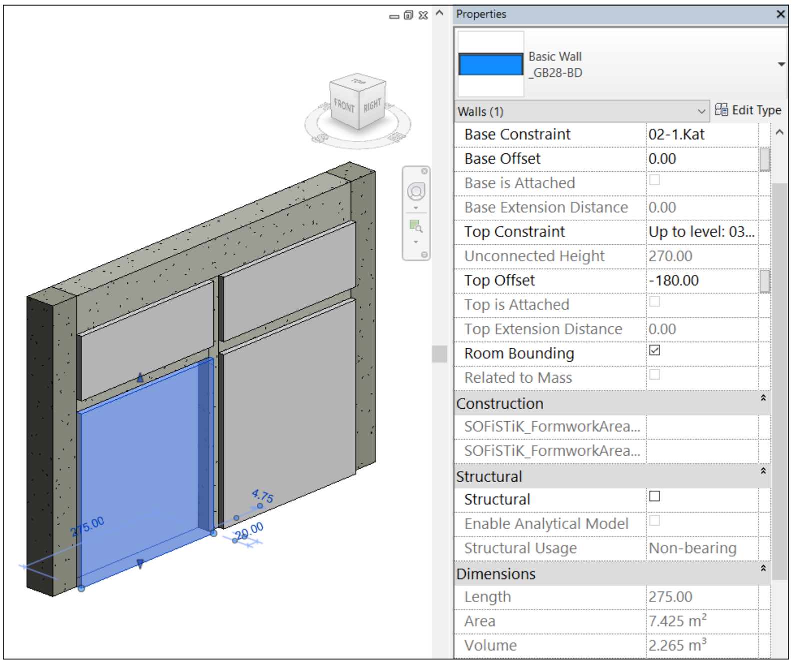


Figure 3.14. Architectural Wall with Coating

3.3.10. Modeling of Facade Insulation with Coatings

After modeling the architectural exterior walls, facade insulation was modeled. Insulation material for facade of the building is rockwool. According to the design of the facade, exterior face of the walls were 7 cm outside of the exterior face of the structural elements. Insulation is only applied to the surface of reinforced concrete elements which are beams, columns, structural walls, vertical and horizontal beams and parapet walls. Thickness of insulation material is also 7 cm and after implementation of rockwool, the exterior face of the walls and rockwools are matching at the same vertical alignment. In order to model the insulation, an architectural wall family was formed and insulation types were created. The material of the facade insulation was selected as rockwool. For exterior plastering and painting, separate layers were created and both plaster and paint were modeled together with the insulation as a 3-layer coating. Figure 3.15 shows an example of the insulation material placed on a reinforced concrete element by including plaster and paint layers on the exterior face. In order to obtain an accurate quantity take-off for rockwool, each piece should be calculated separately and then added up.

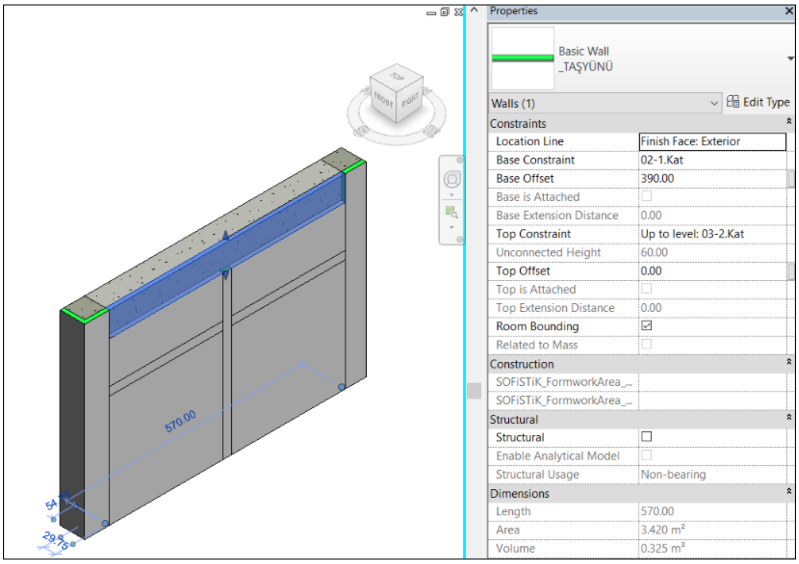


Figure 3.15. An Example Facade Insulation with Plaster and Painting Coatings

In this study, exterior plaster and painting layers of the insulation element are inserted to wall types after modeling the insulation elements. Hence, insulation element types have been updated after modeling them. In this case, corner of the elements having such exterior coatings are not merged properly. Figure 3.16 shows an improper joint of the elements in 2D plan and Figure 3.17 shows it in 3D view. The ‘join’ command is tried to solve the problem but it is seen that join command is not served the purpose for the solution of this problem. Figure 3.18 shows the view of joint in 2D plan after using the join command and Figure 3.19 shows it in 3D plan. As a result, a method has to be developed by using the ‘split’ and ‘extend to corner’ commands. Firstly, a small portion of the elements that are to be joined are split from their endpoints and these parts are deleted from the model. Figure 3.20 shows the split parts of the elements and Figure 3.21 shows in 2D plan the elements after deleting split parts. Later, by using the ‘extend to corner’ command of Revit, these corners are joined properly. Figure 3.22 and 3.23 shows a proper joint of elements in 2D and 3D plan, respectively.

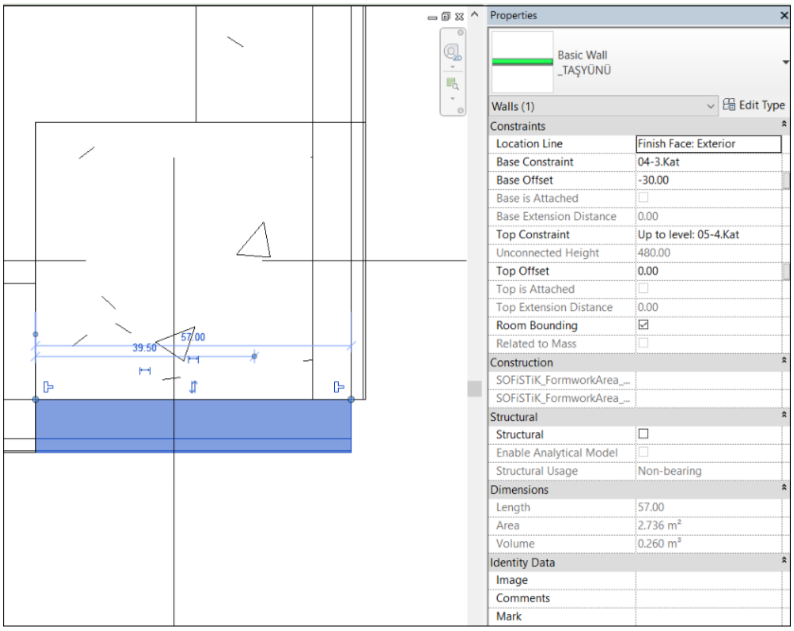


Figure 3.16. An Improper Joint of Insulation Elements in 2D Plan

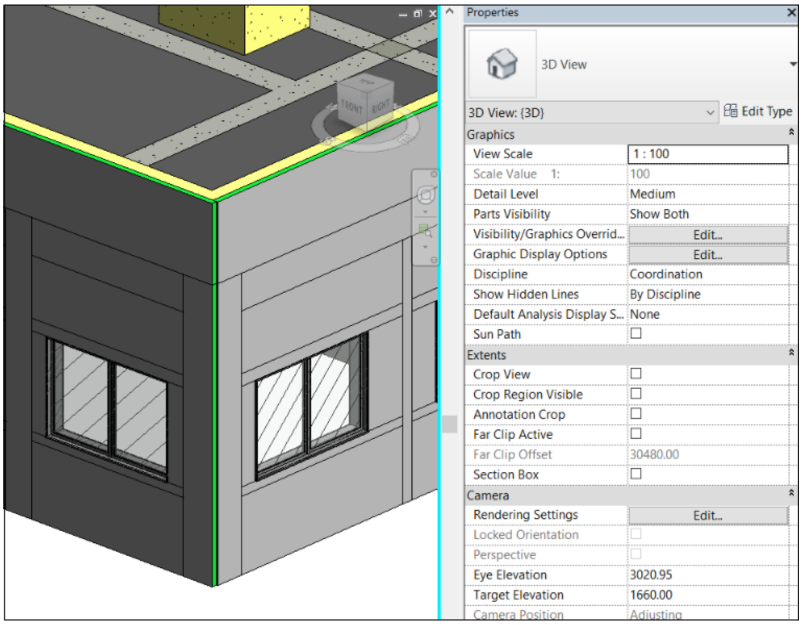


Figure 3.17. An Improper Joint of Insulation Elements in 3D Plan

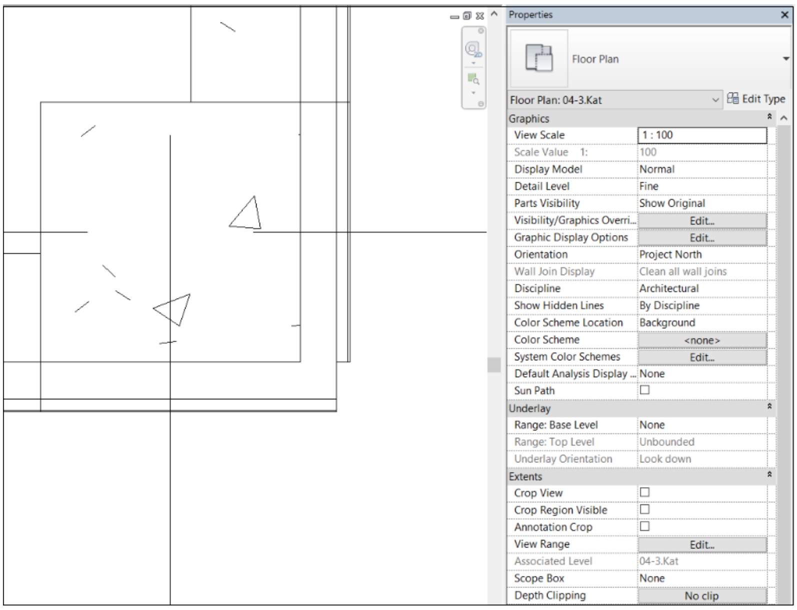


Figure 3.18. An Improper Joint of Insulation Elements in 2D Plan (after Join Command)

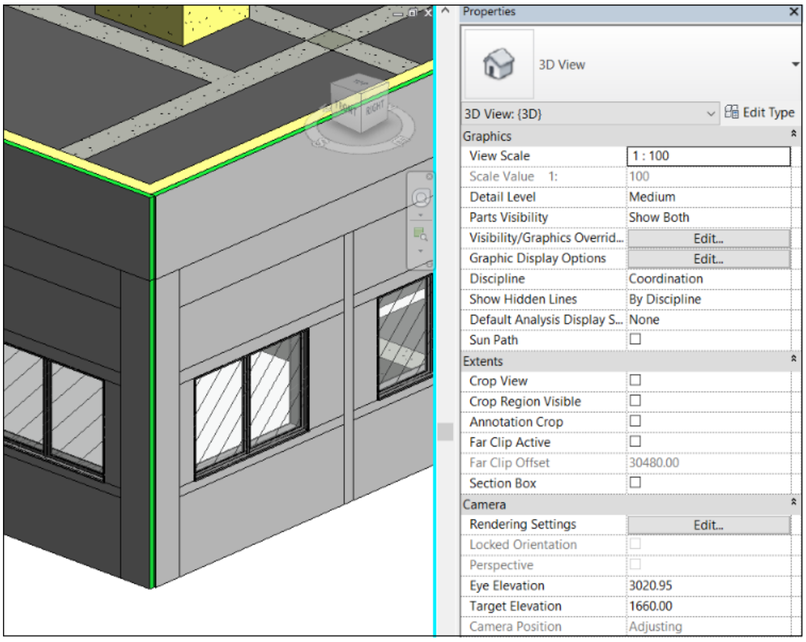


Figure 3.19. An Improper Joint of Insulation Elements in 3D Plan (after Join Command)

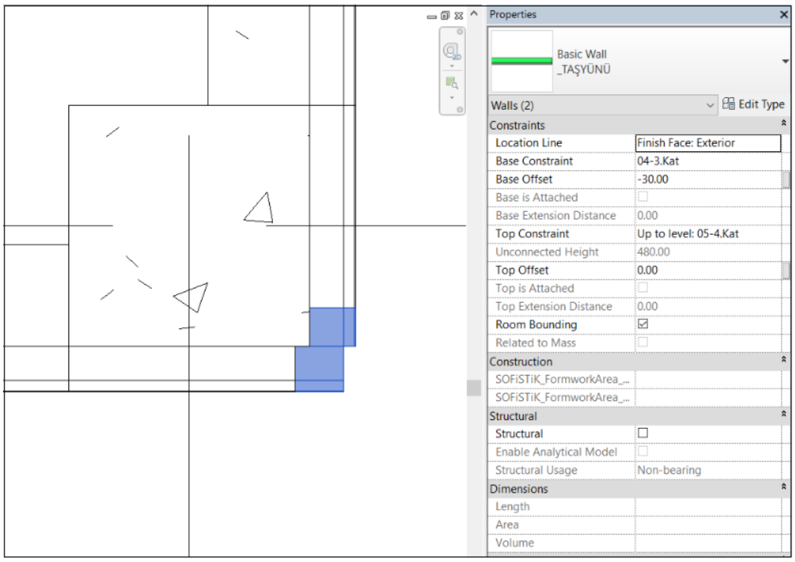


Figure 3.20. Split Sections of Elements in 2D Plan

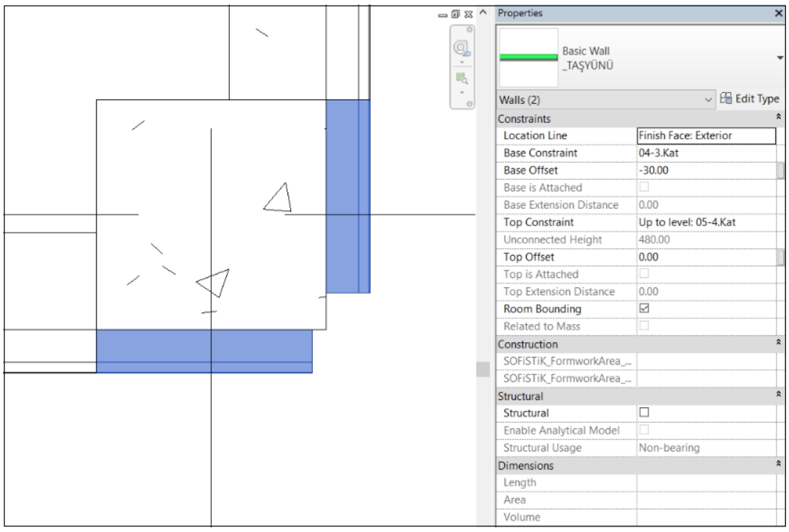


Figure 3.21. Elements after Deleting Split Sections in 2D Plan

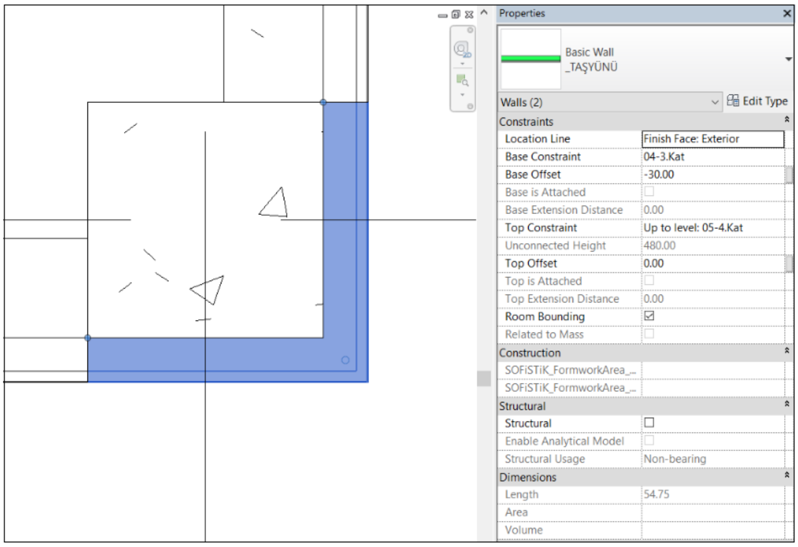


Figure 3.22. A Proper Joint of Insulation Elements in 2D Plan

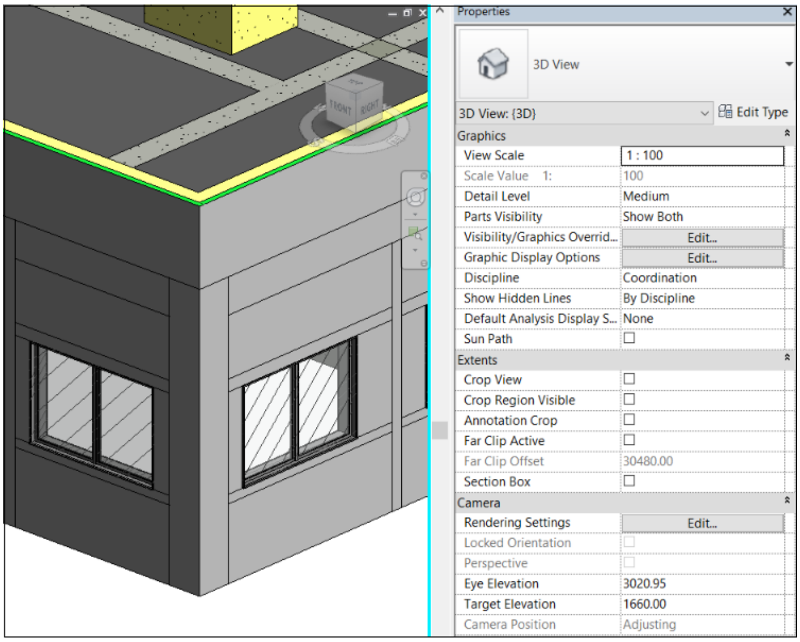


Figure 3.23. A Proper Joint of Insulation Elements in 3D Plan

Moreover, another solution is deleting the insulation elements located in corners and modeling again after inserting exterior layers to all types which is also a time-consuming process in our case. Nevertheless, It might be a better practice to identify exterior coating layers of the insulation element before modeling so as to plan modeling better and to not to face with this type of situations.

3.3.11. Modeling of Curtain Walls and Windows

Just after modeling the exterior walls and facade insulation, the curtain walls and windows which are made of aluminum frames and glass were modeled. In order to model the curtain walls and windows, a window family was formed and curtain wall and window types were created according to their sizes. Material of the curtain walls was selected as aluminum and glass. There should be a wall at the place of windows to be a guide in order to be able to model a window or curtain wall on a facade. Since the exterior walls were modeled in parts, walls were also modeled at the place of the windows. The windows and curtain walls were placed on the facade according to their locations. The aluminum Headwalls were also modeled as windows. Figure 3.24 shows an example of the exterior windows modeled on the facade.

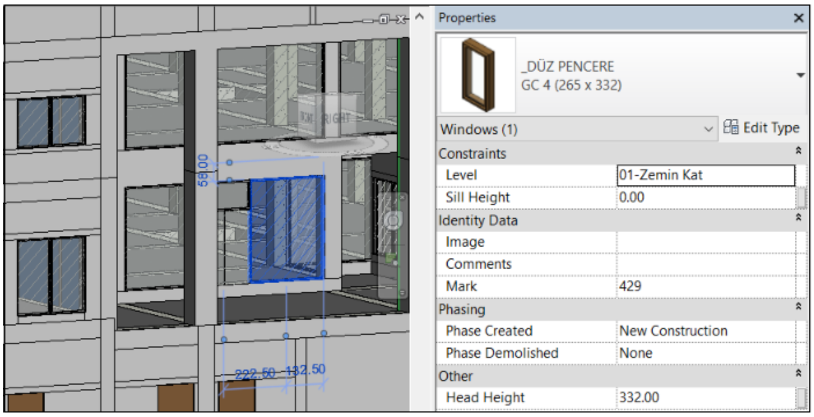


Figure 3.24. An Exterior Windows

3.3.12. Modeling of Exterior Doors

Lastly, the exterior doors which are fire doors and metal doors were modeled on the facade. In order to model doors, a door family was formed and door types were created according to size and other features of the doors. Like windows, there should be a wall at the place of to be modeled door as a guide. Therefore, walls were modeled at existing places of the doors. Figure 3.25 shows an example of the exterior doors.

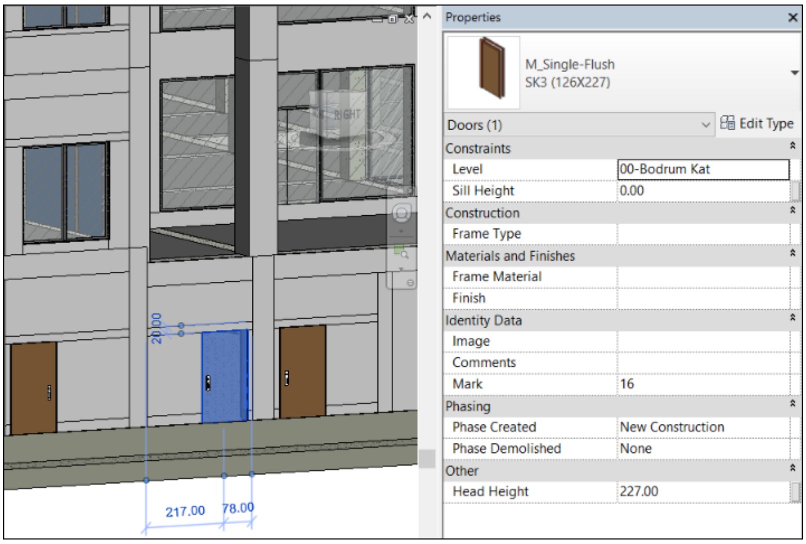


Figure 3.25. An Exterior Doors

3.4. Major Challenges and Corresponding Solutions

There are challenges which are encountered during the case study. Some of them are faced with in modeling process and some of them came along during the extraction of quantities from the model.

Some challenges confronted during the modeling process are mentioned in section 3.3 while explaining modeling process of work items in scope of this study. In the course of modeling foundation, it is determined that there is no availability to open wall openings on structural slab foundation elements and therefore foundation walls having openings were modeled as structural wall elements as it is demonstrated in Figure 3.2. While modeling exterior walls, it is seen that the area of the vertical and horizontal beams are not being deducted from the area of the walls when the beams are modeled over the walls. Since the walls are placed at 7 cm outside of the structural framework, the ‘join’ command has not solved the problem. Therefore, architectural walls are modeled piece by piece after modeling vertical and horizontal beams to achieve accurate QTO results. The walls modeled in parts can also be seen in Figure 3.13. While modeling the insulation materials with coating on its facade, it is determined that coating (plaster and paint) layer needs to be inserted to insulation element types before modeling in order to obtain proper view and correct quantities. Figure 3.17 shows the view of an improper joint of insulation elements and Figure 3.23 shows the view of a proper joint of insulation elements in 3D plan.

Modeling of structural elements is the main part of this study. After modeling the structural elements, it is easy to extract concrete quantities from Revit model. However, the lack of the feature to obtain formwork quantities in Revit is one of the major challenge encountered with during the study. In order to handle with this shortcoming, a set of free tools named as “Sofistik Bimtools” which includes formwork area calculation tool for Autodesk Revit is installed to the Revit 2017. By the help of this plugin, formwork areas of foundation, columns, beams, slabs, structural walls etc. can be obtained from model. In order to obtain the quantities, formwork area tool needs to be run after selecting structural elements that the quantities will be calculated for. After running the tool, the calculation is made automatically and the result is saved within the properties of the elements. The quantities can be extracted from the model with the export tool of the program. However, there are some difficulties experienced while using the formwork area tool. The main difficulty is regarding the calculation time of the tool. If all structural elements are selected, calculation takes too much time. Calculation could not be performed for all structural elements of the model used in this study at once, since the program failed during the calculation process. Therefore, the tool is run by selecting each floor separately and although the calculation is performed in parts, the process still took tens of minutes for each floor. The isolated view of first level of the building for the execution of the calculation process can be seen as an example in Figure 3.26.

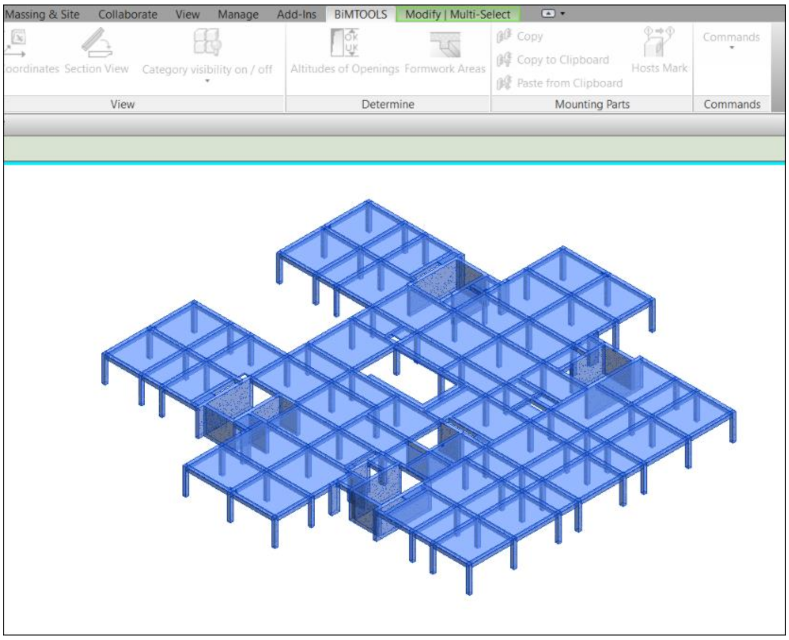
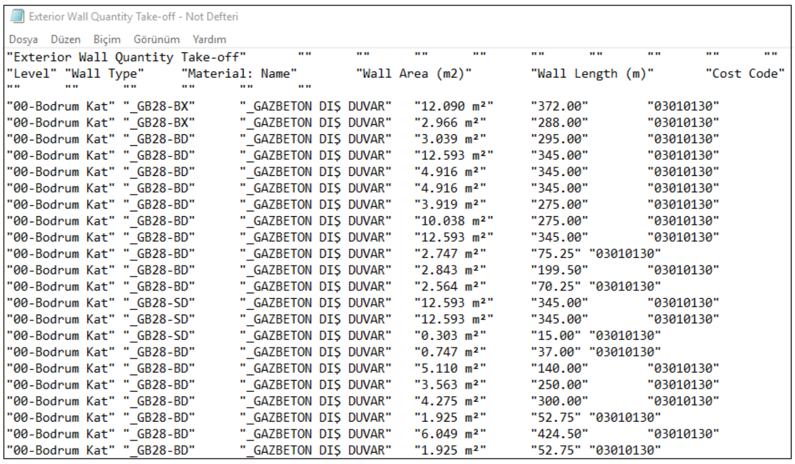


Figure 3.26. The Isolated View of 1st Level of Building

The other difficulty is that when there is a correction or revision in the element, calculation needs to be performed again. Even if the change is done in the identity data of the element, the calculated formwork quantity of the element is becoming zero. Besides, the calculation is required to be performed by selecting all interrelated elements in that floor of the building. The calculation that is performed by selecting only partial elements in the floor gives inaccurate results. Therefore, when there is a change in one single element, tool is required to be run for the whole floor and it means that there is a need for tens of minutes in each time. There are also some other deficiencies faced with during the usage of formwork area tool which will be discussed in Chapter 4 while comparing quantities obtained from Revit and Allplan model.

The other challenge is about the extraction of quantities from the model. In Revit, quantities are extracted as .txt file and these data are in raw data format. Figure 3.27 shows the example of QTO data in .txt format. In order to use those, data needs to be transferred to another program such as Microsoft Excel. After transferring the data, some operations are required such as changing decimal points from point to comma. Therefore, when there is a change in the model, these operations need to be repeated in order to get a usable quantity take-off list, hence this is a time-consuming task.


Exterior Wall Quantity Take-off - Not Defteri
Dosya Düzen Biçim Görünüm Yardım

```
"Exterior Wall Quantity Take-off"	""	""	""	""	""	""	""	""	""
"Level"	"Wall Type"	"Material: Name"	"Wall Area (m2)"	"Wall Length (m)"	"Cost Code"
""	""	""	""	""	""

"00-Bodrum Kat"	"_GB28-BX"	"_GAZBETON DIŞ DUVAR"	"12.090 m²"	"372.00"	"03010130"
"00-Bodrum Kat"	"_GB28-BX"	"_GAZBETON DIŞ DUVAR"	"2.966 m²"	"288.00"	"03010130"
"00-Bodrum Kat"	"_GB28-BD"	"_GAZBETON DIŞ DUVAR"	"3.039 m²"	"295.00"	"03010130"
"00-Bodrum Kat"	"_GB28-BD"	"_GAZBETON DIŞ DUVAR"	"12.593 m²"	"345.00"	"03010130"
"00-Bodrum Kat"	"_GB28-BD"	"_GAZBETON DIŞ DUVAR"	"4.916 m²"	"345.00"	"03010130"
"00-Bodrum Kat"	"_GB28-BD"	"_GAZBETON DIŞ DUVAR"	"4.916 m²"	"345.00"	"03010130"
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"00-Bodrum Kat"	"_GB28-BD"	"_GAZBETON DIŞ DUVAR"	"0.747 m²"	"37.00"	"03010130"
"00-Bodrum Kat"	"_GB28-BD"	"_GAZBETON DIŞ DUVAR"	"5.110 m²"	"140.00"	"03010130"
"00-Bodrum Kat"	"_GB28-BD"	"_GAZBETON DIŞ DUVAR"	"3.563 m²"	"250.00"	"03010130"
"00-Bodrum Kat"	"_GB28-BD"	"_GAZBETON DIŞ DUVAR"	"4.275 m²"	"300.00"	"03010130"
"00-Bodrum Kat"	"_GB28-BD"	"_GAZBETON DIŞ DUVAR"	"1.925 m²"	"52.75"	"03010130"
"00-Bodrum Kat"	"_GB28-BD"	"_GAZBETON DIŞ DUVAR"	"6.049 m²"	"424.50"	"03010130"
"00-Bodrum Kat"	"_GB28-BD"	"_GAZBETON DIŞ DUVAR"	"1.925 m²"	"52.75"	"03010130"
```

Figure 3.27. Exterior Wall Data in .txt Format

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Comparison of QTO Results

In this part of the thesis, the quantities of the modeled items in the scope of the case study which are obtained from Revit and Allplan models are compared and the differences of the results are discussed.

4.1.1. Comparison of Foundation Quantity Take-off

Foundation type of the building is strip foundation and some parts of the foundation is mat foundation. Modeling of foundation is quite difficult due to the existence of various size of beams and slabs having different heights. The general view of the foundation is already given in Figure 3.1. There is a slab on grade at the upper level of the foundation which has a height of 0.2 m. Figure 4.1 shows a view of the foundation with slab on grade.

Formwork area and concrete volume of the foundation are compared as part of the foundation QTO. Foundation can be grouped into 4 parts which are beams, mat foundation, structural wall, and slab on grade. Table 4.1 shows a comparison of quantities obtained from Revit and Allplan models.

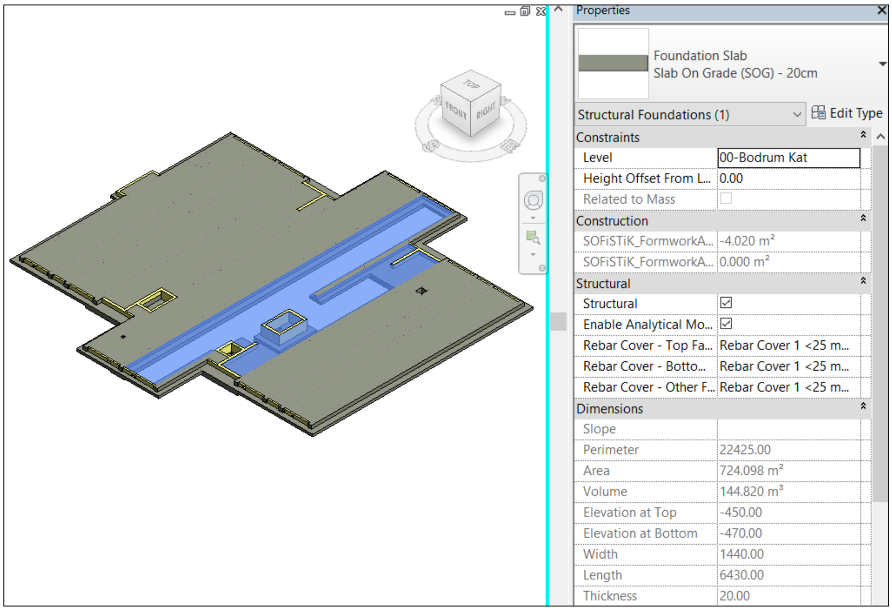

Figure 4.1. Foundation with Slab on Grade

Table 4.1. *Comparison of Formwork Area and Concrete Volume of Foundation*

Foundation Part	**Formwork Area (m^2) Revit**	**Formwork Area (m^2) Allplan**	**Concrete Volume (m^3) Revit**	**Concrete Volume (m^3) Allplan**
Beams	908.53	905.58	352.86	350.68
Mat Foundation	672.82	673.76	1237.46	1237.64
Structural Wall	69.17	69.39	18.01	18.13
Slab on Grade	0.00	0.00	531.29	532.00
Total	**1650.52**	**1648.73**	**2139.62**	**2138.45**
Difference (Revit-Allplan) - (unit)	**1.78 m^2**		**1.17 m^3**	
Difference (Revit-Allplan) - (%)	**0.11%**		**0.05%**	

As it is seen in Table 4.1, quantities of the formwork area obtained from Revit model is 0.11% more than the quantities obtained from Allplan and quantities of concrete volume obtained from Revit model is 0.05% more than the quantities obtained from

Allplan. Overall, the quantities obtained from Revit and Allplan models are nearly same. Since the difference is less than 1%, it is accepted as negligible. Therefore, it can be concluded that quantities obtained from both models for the foundation are accurate and can be used during the execution of the project.

4.1.2. Comparison of Column Quantity Take-off

Formwork area and concrete volume of columns are extracted from Revit and Allplan models and also a comparison table which shows the quantities and their differences is generated. Columns were already named according to numbers written on the project drawings. Therefore, comparison could be carried out for each column separately. Table 4.2 includes information regarding level of columns, column names, quantities, difference of quantities, and ratio of total differences. The comparison table only shows the columns having different quantities in terms of formwork area and concrete volume. There are 393 columns as a total in the building and only the columns having different quantities are examined and checked by manual calculations.

As it is seen in the comparison table, there are differences in formwork area of 9 columns. The reasons of differences in formwork areas are examined and it is observed that all of the 9 differences (8 of them in Allplan model, 1 of them in Revit Model) arise from modeling mistakes. Figure 4.2 shows an example of modeling mistake in Allplan model which is related to the height of the column. There is a low floor at the location of columns and it is overlooked and therefore the height of the columns are modeled wrong.

Table 4.2. *Columns with Different Formwork Area and/or Concrete Volume*

Level	Column Name	Formwork Area (m^2) Revit	Formwork Area (m^2) Allplan	Difference of Formwork Areas (m^2) Revit-Allplan	Concrete Volume (m^3) Revit	Concrete Volume (m^3) Allplan	Difference of Concrete Volumes (m^3) Revit-Allplan
Basement	S11	13.47	13.67	-0.20	3.15	3.15	0.00
1st Floor	S1	8.90	8.40	0.50	1.19	1.13	0.06
1st Floor	S2	8.60	8.10	0.50	1.19	1.13	0.06
1st Storey	S3	8.90	8.40	0.50	1.19	1.13	0.06
2nd Storey	S65	9.00	9.15	-0.15	1.25	1.25	0.00
3rd Storey	S74	8.70	8.10	0.60	1.20	1.13	0.08
3rd Storey	S75	9.00	8.40	0.60	1.20	1.13	0.08
Roof	S11	7.75	8.08	-0.32	1.13	1.13	0.00
Roof	S82	7.59	7.92	-0.33	1.13	1.13	0.00
	Total	**3409.29**	**3407.61**	**1.68**	**513.41**	**513.07**	**0.34**
Ratio of Difference (%) (Revit - Allplan)		**0.05%**			**0.07%**		

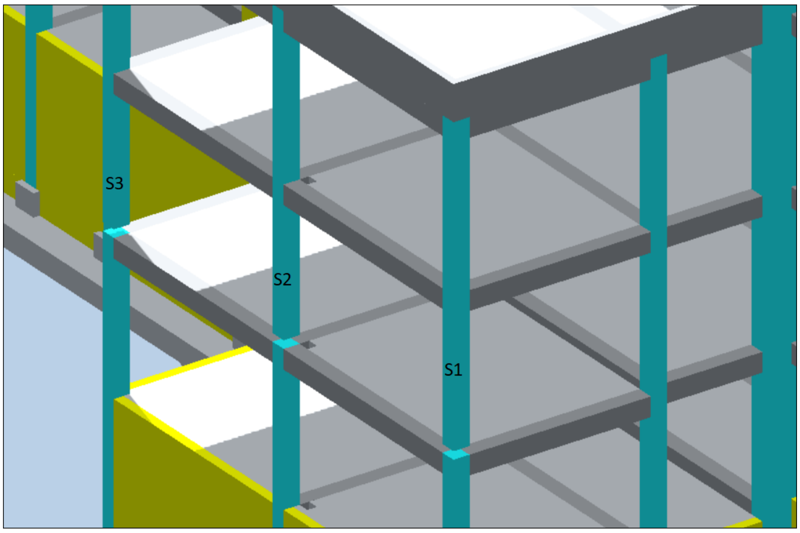

Figure 4.2. Modeling Mistake in the Height of the Columns in Allplan Model

In addition, formwork area of the two columns in roof level which are S11 and S82 are calculated wrong in Allplan model since the parapet walls are joined inside of the columns. Formwork area of S11 column is calculated as 8.075 m^2 by Allplan due to this human error. Figure 4.3 shows an example of modeling mistake in joint of S11 column and parapet wall in Allplan. When the modeling mistake is rectified, the correct result which is 7.75 m^2 is obtained.

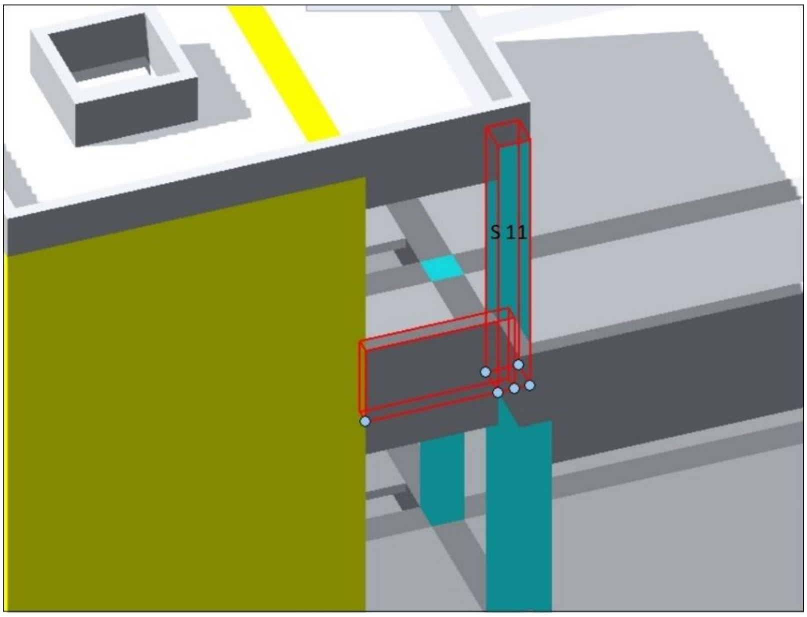

Figure 4.3. Modeling Mistake in Joint of Column and Parapet Wall in Allplan Model

Apart from these, there is a possibility to face with errors originated from formwork Apart from the foregoing remarks, there is a possibility to incur errors originated from the formwork area tool in Revit. Formwork area tool is a part of Sofistik Bimtools add-in which is used for calculating formwork area in Revit. Formwork area of 2 columns located on roof level are calculated as incorrect with the tool when the tool is run by selecting 3rd floor and roof together. The reason of the mistake is not understood and it is presumed as a software error. Figure 4.4 shows an incorrect result of the formwork area calculation of the S11 column in Revit. Formwork area is calculated as 5.5 m^2 by the tool however the actual area is 7.75 m^2.

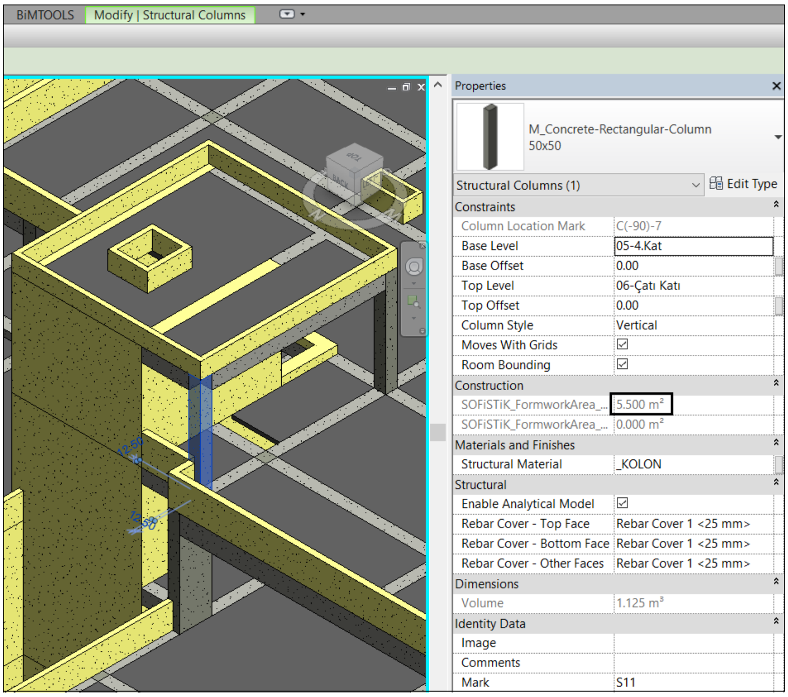

Figure 4.4. Incorrect Formwork Area of S11 Column in Revit Model

Formwork area of S65 column which is located on the 2nd floor is wrong due to a modeling mistake in Revit model. Figure 4.5 shows a view of the column and resulting formwork area. Formwork area of the column is calculated as 9.00 m^2. The upper level of the beam in the left side of the column should be 30 cm lower in order to be at the same level with the low floor. Therefore, the real formwork area of the column needs to be 9.15 m^2. If the level of the beam is corrected, the correct result can be achieved.

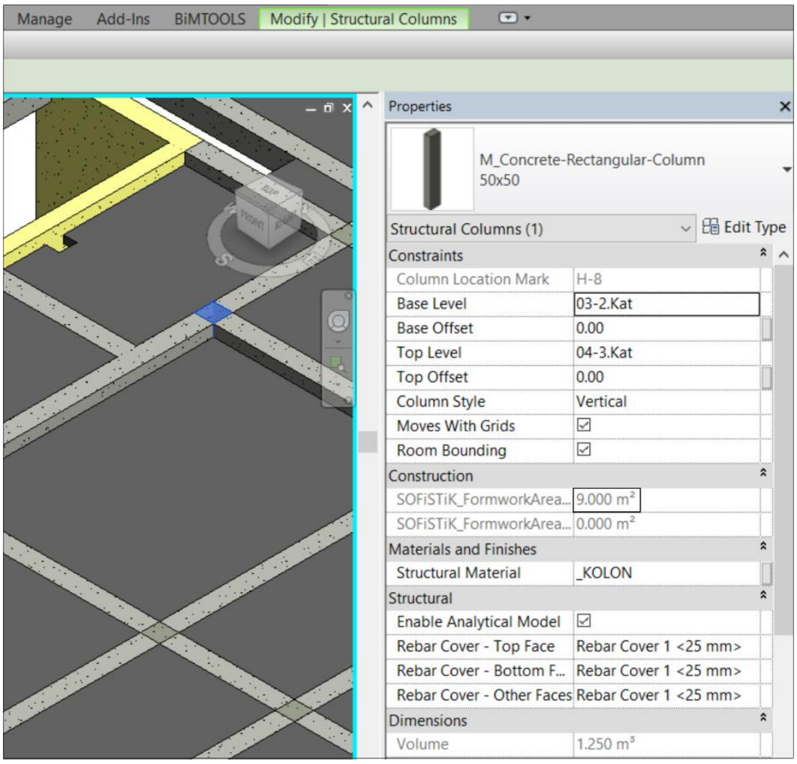

Figure 4.5. Incorrect Formwork Area of S65 Column in Revit Model

As seen in Table 4.2, there are differences in concrete volume of 5 columns. The reasons of differences in concrete volume quantities are investigated and it is observed that all of the differences are originated from modeling mistakes in Allplan model. One of the example is given in Figure 4.2, height of the columns are modeled 25 cm shorter than their real height due to a modeling mistake. Therefore, concrete volume of these columns are 0.06 m^3 less than their real volume.

As a result, total formwork areas of columns in Revit model is 1.68 m^2 more than Allplan model and the ratio of difference is 0.05%. Similarly, the concrete volume of columns in Revit model is 0.34 m^3 more than Allplan model and the ratio of difference is 0.07%. It can be concluded that all differences arise from human errors and when human errors are eliminated there is no difference in quantities. Therefore, it can be stated that formwork area and concrete volume quantities obtained from Allplan and Revit models for the columns are accurate and can be used reliably during the execution of the project.

4.1.3. Comparison of Structural Wall Quantity Take-off

Formwork area and concrete volume of structural walls are extracted from Revit and Allplan models and a comparison table which shows the quantities and their differences is generated as well. There is no markings on the project drawings for structural walls, therefore structural walls were named according to the numbers given on the Allplan model to make an accurate comparison. In this way, comparison could be carried out for each structural wall separately. Table 4.3 includes information regarding level of structural walls, structural wall names, quantities, difference of quantities, and ratio of total differences. The table is filtered and only structural walls having differences in quantities are shown. There are 28 pieces of structural walls in the building and only structural walls having different quantities are examined and checked by manual calculations.

As it is seen in the comparison table, there are differences in formwork area of 18 structural walls. The reasons of differences in formwork areas are reviewed and it is observed that 7 of the differences arise from modeling mistakes in Allplan model, 9 of the differences arise from formwork area tool errors in Revit and 2 of the differences results from both of these.

Table 4.3. *Structural Wall with Different Formwork Area and Concrete Volume*

Level	Structural Wall Name	Formwork Area (m^2) Revit	Formwork Area (m^2) Allplan	Difference of Formwork Areas (m^2) Revit-Allplan	Concrete Volume (m^3) Revit	Concrete Volume (m^3) Allplan	Difference of Concrete Volumes (m^3) Revit-Allplan
Basement	P3	248.14	251.81	-3.67	62.20	62.20	0.00
Basement	P4	247.02	250.69	-3.67	60.67	60.67	0.00
Basement	P5	117.14	116.64	0.50	26.33	26.33	0.00
Basement	IP01-IP02-IP03	918.19	920.77	-2.58	145.50	145.50	0.00
Ground Floor	P1	174.17	177.78	-3.61	43.24	43.24	0.00
Ground Floor	P2	173.04	176.71	-3.67	43.24	43.24	0.00
Ground Floor	P3	254.50	254.32	0.17	63.79	63.79	0.00
Ground Floor	P4	253.37	252.79	0.58	62.26	62.26	0.00
Ground Floor	P5	117.14	117.05	0.09	26.33	26.33	0.00
1st Floor	P5	116.56	116.47	0.09	26.33	26.33	0.00
2nd Floor	P2	199.82	199.34	0.48	49.81	49.74	0.07
2nd Floor	P4	280.93	281.56	-0.63	69.18	69.18	0.00
2nd Floor	P5	129.87	129.78	0.09	29.25	29.25	0.00
3rd Floor	P1	169.69	169.77	-0.08	42.81	42.81	0.00
3rd Floor	P3	236.00	247.93	-11.93	63.36	63.36	0.00
3rd Floor	P4	247.79	247.55	0.24	60.95	60.95	0.00
3rd Floor	P5	120.29	120.19	0.09	27.90	27.90	0.00
Roof	P4	190.04	188.26	1.78	48.28	48.74	-0.46
	Total	**6233.88**	**6259.60**	**-25.71**	**1463.09**	**1463.47**	**-0.39**
Ratio of Difference (%) (Revit - Allplan)		**-0.41%**			**-0.03%**		

Modeling mistakes in Allplan affecting the formwork area calculation of structural walls result from missing shaft openings in floors, forgotten floors, or incorrect floor thicknesses. Figure 4.6 shows an example of modeling mistake in Allplan due to missing a shaft opening in the floor. The missing shaft opening is at the boundary of the structural wall P4 on the ground floor. When the shaft opening is modeled, formwork area of the structural wall in Allplan model increases by 0.579 m^2 which is same as the difference observed in the comparison table.

Figure 4.7 shows an example of modeling mistake in Allplan due to forgotten floor. Floor D 472 is overlooked in Allplan model. Since two sides of the missing floor is adjacent to structural wall P4 on the second floor, formwork area of the structural wall is calculated 0.63 m^2 more than its real value. When the floor is modeled, the difference in the formwork area of the structural wall which can also be seen in Table 4.3, becomes zero.

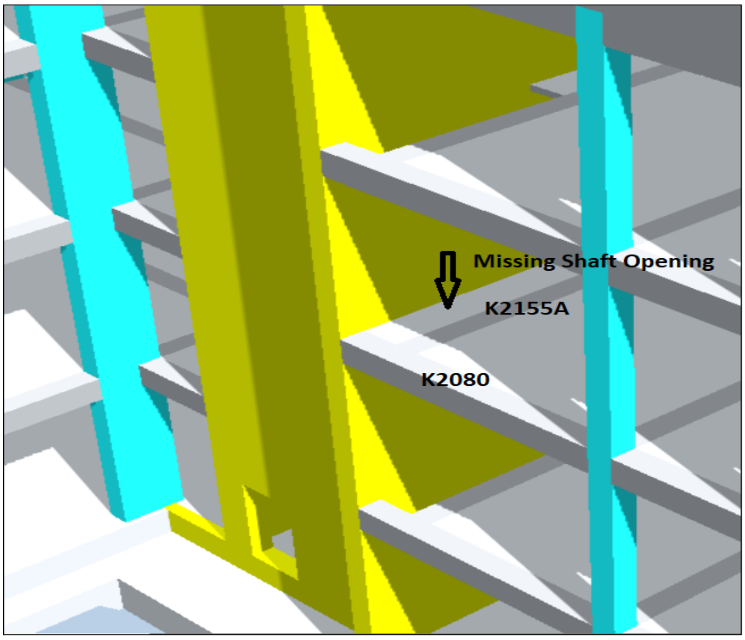

Figure 4.6. Missing Shaft Opening in Allplan Model

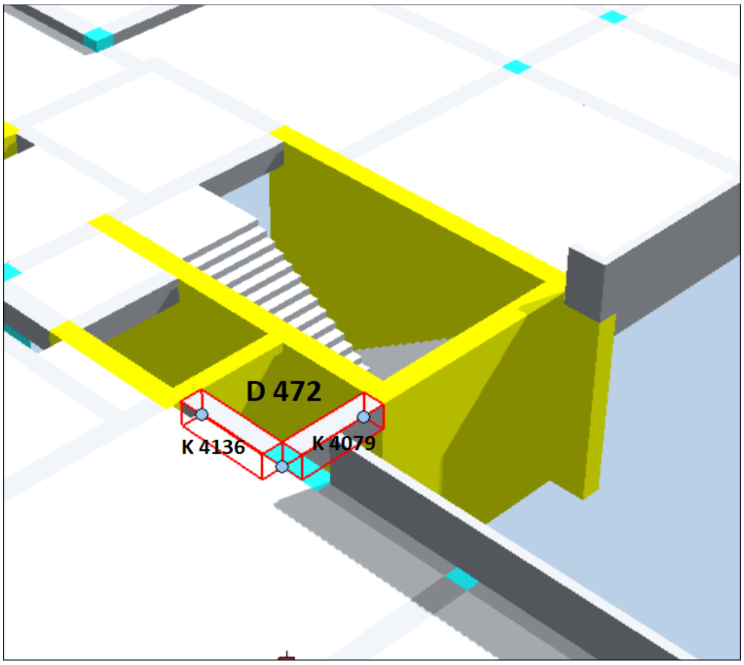

Figure 4.7. Missing Floor in Allplan Model

Formwork area tool errors in Revit are originated from the add-in software. The reason of some errors are not understood exactly. Formwork area of some structural walls are calculated wrong by the tool. Figure 4.8 shows an example of structural wall whose formwork area is calculated wrong. Formwork area of a part of the structural wall P3 located on 3rd floor is calculated as 6.673 m^2 by the tool however the correct formwork area is 18.598 m^2. The difference is 11.925 m^2 which is also shown in Table 4.3. Furthermore, if the formwork area tool is run by selecting only the related elements but not the whole floor, formwork area of the structural wall is calculated correctly. Figure 4.9 shows the correct results of the formwork area of the structural wall. This method is not a rational solution for these errors because firstly the inaccurate quantities should be determined by manual check for each element and this process is pretty time-consuming. Moreover, for accurate calculation of formwork area of some components, the whole floor has to be selected.

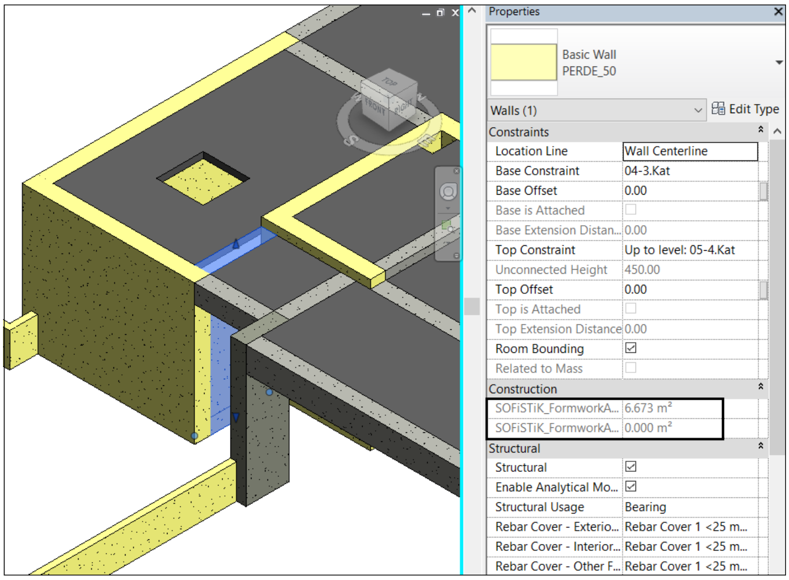

Figure 4.8. Miscalculated Formwork Area of Structural Wall in Revit Model

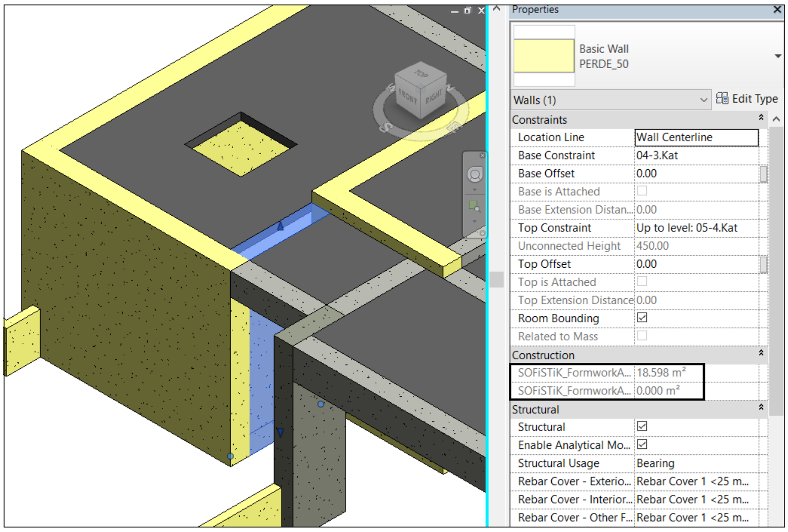

Figure 4.9. Corrected Formwork Area of Structural Wall in Revit Model

Figure 4.10 shows another example of structural wall. Formwork area of the part of structural wall P2 located on ground floor is calculated as 38.79 m^2 by the tool however the correct formwork area is 42.46 m^2. The difference is 3.67 m^2 as can also be seen in Table 4.3. When the difference is analyzed, it can be inferred that area of the formwork required for the sides of the door opening is not considered by the formwork area tool. Therefore, formwork area of the structural wall is calculated 3.67 m^2 less than its real value.

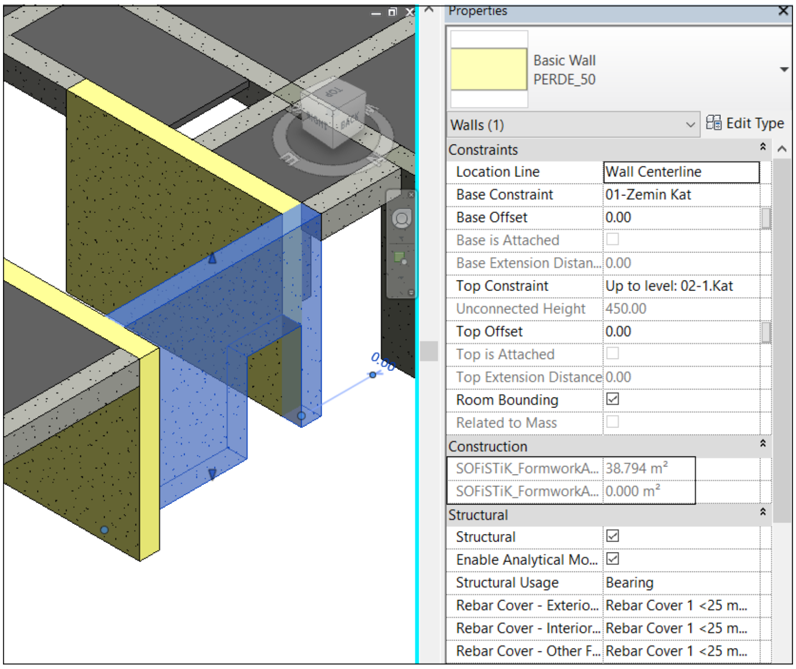

Figure 4.10. Miscalculated Formwork Area of Structural Wall in Revit Model

According to Table 4.3, there are differences in concrete volume of 2 structural walls. The reasons of differences in concrete volume quantities are investigated and it is observed that all of the differences are originated from modeling mistakes in Allplan model. Figure 4.11 shows an example of modeling mistake of structural wall P4 located on roof level. The concrete volume of structural wall is calculated 0.46 m^3 more than it should be. Bottom of the middle section of the structural wall needs to be modeled 27 cm higher since the structural wall in the lower floor is modeled up to that level. When the level of structural wall is corrected, the accurate quantity is obtained.

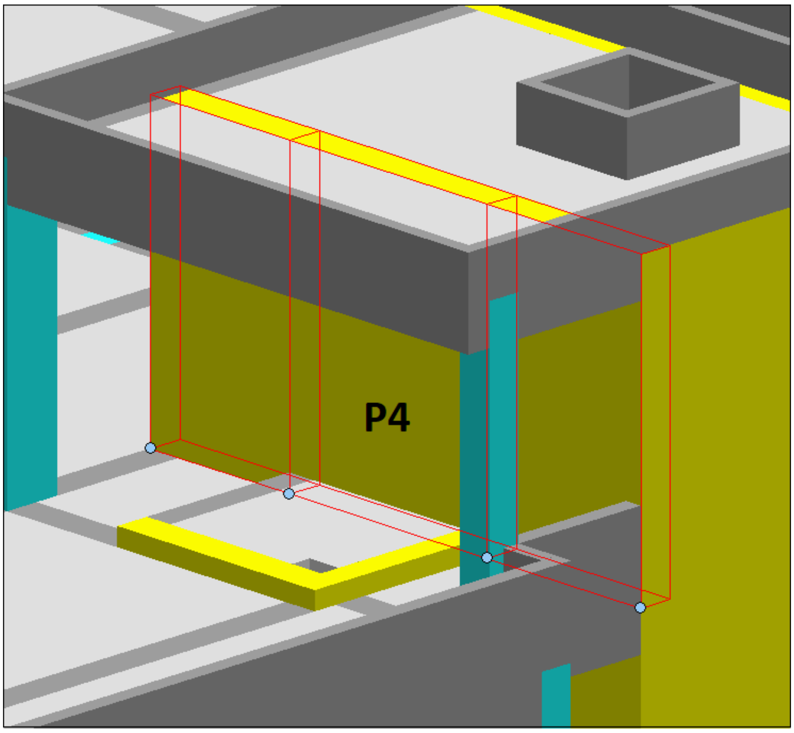

Figure 4.11. Incorrect Level of Structural Wall in Allplan Model

To sum up, total formwork area of structural walls in Revit model is 25.71 m^2 less than Allplan model and the ratio of difference is -0.41% as well as the concrete volume of structural walls in Revit model is 0.39 m^3 less than Allplan model with a ratio of difference of -0.03%. The major difference in formwork area quantities arises from calculation errors of formwork area tool in Revit. Although the difference in formwork area quantities is less than 1%, the difference is considerable. The tool error may cause bigger differences in other buildings since the reason of error is not clearly understood. Therefore, in order to rely on the results obtained for formwork area, it seems that there is a need for an updated version of the add-in to prevent such errors. The difference in concrete volume is very small and when the human errors are eliminated there is no difference in quantities. Eventually, concrete volumes obtained from both

BIM models and formwork area quantities obtained from Allplan model are accurate and can be smoothly used but formwork areas obtained from Revit model needs to be checked and verified during the execution of the project.

4.1.4. Comparison of Beam Quantity Take-off

Formwork area and concrete volume of beams are extracted from Revit and Allplan models and also a comparison table which shows the quantities and their differences is generated. Beams were named according to the numbers written on the project and by this way comparison could be carried out for each beam separately. Table 4.4 includes information regarding level of beams, beam names, quantities, difference of quantities, and ratio of total differences. The table is filtered and only beams having different quantities are shown. There are 814 beams as a total in the building and only beams having different quantities are analyzed and checked by manual calculations.

As it is seen in the comparison table, there are differences in formwork area of 86 beams. The reasons of differences in formwork areas are examined and it is observed that 22 of the differences arise from modeling mistakes in Allplan model, 60 of the differences arise from formwork area tool error in Revit and 4 of the differences arise from both of these.

Table 4.4. *Beams with Different Formwork Area and/or Concrete Volume*

Level	Beam Name	Formwork Area (m^2) Revit	Formwork Area (m^2) Allplan	Difference of Formwork Areas (m^2) Revit-Allplan	Concrete Volume (m^3) Revit	Concrete Volume (m^3) Allplan	Difference of Concrete Volumes (m^3) Revit-Allplan
Basement	K1003	14.91	15.11	-0.20	3.55	3.55	0.00
Basement	K1004	14.91	10.65	4.26	3.55	2.13	1.42
Basement	K1011	7.47	7.41	0.06	1.70	1.70	0.00
Basement	K1029	2.04	4.14	-2.10	0.90	0.90	0.00
Basement	K1030	3.86	7.58	-3.72	1.71	1.71	0.00
Basement	K1039	2.04	4.14	-2.10	0.90	0.90	0.00
Basement	K1048	2.61	5.16	-2.55	1.13	1.13	0.00
Basement	K1050	2.04	4.14	-2.10	0.90	0.90	0.00
Basement	K1058	2.04	4.14	-2.10	0.90	0.90	0.00
Basement	K1059	0.14	7.58	-7.44	1.71	1.71	0.00
Basement	K1061	4.78	4.63	0.15	1.13	1.13	0.00
Basement	K1079	1.65	3.18	-1.53	0.62	0.62	0.00
Basement	K1080	1.65	3.18	-1.53	0.62	0.62	0.00
Basement	K1149	5.00	4.76	0.24	0.92	0.92	0.00
Basement	K1150	6.66	6.25	0.41	1.20	1.20	0.00
Ground Floor	K2008	1.65	3.18	-1.53	0.62	0.62	0.00
Ground Floor	K2009	1.65	3.18	-1.53	0.62	0.62	0.00
Ground Floor	K2048	2.61	5.16	-2.55	1.13	1.13	0.00
Ground Floor	K2060	4.78	4.63	0.15	1.13	1.13	0.00
Ground Floor	K2078	1.65	3.08	-1.43	0.62	0.62	0.00
Ground Floor	K2079	1.65	3.18	-1.53	0.62	0.62	0.00
Ground Floor	K2080	8.51	8.39	0.12	1.71	1.71	0.00
Ground Floor	K2102	10.44	10.38	0.06	2.13	2.13	0.00
Ground Floor	K2112	2.90	2.80	0.11	0.65	0.65	0.00
Ground Floor	K2121	2.40	4.50	-2.10	0.90	0.90	0.00

Table 4.4. *Beams with Different Formwork Area and/or Concrete Volume*

Level	Beam Name	Formwork Area (m^2) Revit	Formwork Area (m^2) Allplan	Difference of Formwork Areas (m^2) Revit-Allplan	Concrete Volume (m^3) Revit	Concrete Volume (m^3) Allplan	Difference of Concrete Volumes (m^3) Revit-Allplan
Ground Floor	K2131	0.07	8.65	-8.58	2.00	2.00	0.00
Ground Floor	K2145	2.40	4.50	-2.10	0.90	0.90	0.00
Ground Floor	K2148	5.00	4.76	0.24	0.92	0.92	0.00
Ground Floor	K2155A	10.17	9.59	0.58	2.13	2.13	0.00
1^{st} Floor	K3008	1.65	3.18	-1.53	0.62	0.62	0.00
1^{st} Floor	K3009	1.65	3.18	-1.53	0.62	0.62	0.00
1^{st} Floor	K3014	9.23	9.59	-0.36	2.13	2.13	0.00
1^{st} Floor	K3015	9.23	9.59	-0.36	2.13	2.13	0.00
1^{st} Floor	K3026	9.23	9.59	-0.36	2.13	2.13	0.00
1^{st} Floor	K3027	9.23	9.59	-0.36	2.13	2.13	0.00
1^{st} Floor	K3048	2.75	5.30	-2.55	1.13	1.13	0.00
1^{st} Floor	K3060	4.93	4.78	0.15	1.13	1.13	0.00
1^{st} Floor	K3078	1.65	3.18	-1.53	0.62	0.62	0.00
1^{st} Floor	K3079	1.65	3.18	-1.53	0.62	0.62	0.00
1^{st} Floor	K3119	6.37	6.60	-0.23	1.40	1.40	0.00
1^{st} Floor	K3130	6.05	6.51	-0.47	1.40	1.40	0.00
1^{st} Floor	K3143	6.37	6.60	-0.23	1.40	1.40	0.00
1^{st} Floor	K3148	4.91	4.76	0.15	0.92	0.92	0.00
2^{nd} Floor	K4008	1.65	3.18	-1.53	0.62	0.62	0.00
2^{nd} Floor	K4009	1.65	3.18	-1.53	0.62	0.62	0.00
2^{nd} Floor	K4022	3.69	7.41	-3.72	1.71	1.71	0.00
2^{nd} Floor	K4023	-0.12	3.99	-4.11	0.90	0.90	0.00
2^{nd} Floor	K4037	4.14	4.05	0.09	0.90	0.90	0.00
2^{nd} Floor	K4048	2.75	5.30	-2.55	1.13	1.13	0.00
2^{nd} Floor	K4056	3.69	7.41	-3.72	1.71	1.71	0.00

Table 4.4. *Beams with Different Formwork Area and/or Concrete Volume*

Level	Beam Name	Formwork Area (m^2) Revit	Formwork Area (m^2) Allplan	Difference of Formwork Areas (m^2) Revit-Allplan	Concrete Volume (m^3) Revit	Concrete Volume (m^3) Allplan	Difference of Concrete Volumes (m^3) Revit-Allplan
2nd Floor	K4057	-0.06	4.14	-4.20	0.90	0.90	0.00
2nd Floor	K4060	4.93	4.78	0.15	1.13	1.13	0.00
2nd Floor	K4078	1.65	3.18	-1.53	0.62	0.62	0.00
2nd Floor	K4079	1.65	3.49	-1.84	0.62	0.62	0.00
2nd Floor	K4136	3.00	3.33	-0.32	0.65	0.65	0.00
2nd Floor	K4148	4.91	4.76	0.15	0.92	0.92	0.00
2nd Floor	K4150	7.41	6.66	0.75	1.76	1.53	0.23
2nd Floor	K4160	9.44	9.23	0.21	2.13	2.13	0.00
2nd Floor	K4164	-0.15	4.05	-4.20	0.90	0.90	0.00
2nd Floor	K4165	0.32	9.44	-9.12	2.13	2.13	0.00
2nd Floor	K4166	-0.06	4.14	-4.20	0.90	0.90	0.00
2nd Floor	K4167	0.32	9.23	-8.91	2.13	2.13	0.00
3rd Floor	K5001	1.65	3.18	-1.53	0.62	0.62	0.00
3rd Floor	K5002	14.02	13.82	0.20	2.94	2.94	0.00
3rd Floor	K5003	14.02	13.82	0.20	2.94	2.94	0.00
3rd Floor	K5004	1.65	3.18	-1.53	0.62	0.62	0.00
3rd Floor	K5006	4.67	9.23	-4.56	2.13	2.13	0.00
3rd Floor	K5007	4.67	9.23	-4.56	2.13	2.13	0.00
3rd Floor	K5015	10.04	10.00	0.04	2.13	2.13	0.00
3rd Floor	K5031	2.33	4.88	-2.55	1.13	1.13	0.00
3rd Floor	K5043	2.77	2.67	0.10	0.62	0.62	0.00
3rd Floor	K5047	4.40	4.18	0.23	0.84	0.84	0.00
3rd Floor	K5048	4.36	8.65	-4.29	2.00	2.00	0.00
3rd Floor	K5049	4.43	8.78	-4.35	2.03	2.03	0.00
3rd Floor	K5050	1.65	3.18	-1.53	0.62	0.62	0.00

Table 4.4. *Beams with Different Formwork Area and/or Concrete Volume*

Level	Beam Name	Formwork Area (m^2) Revit	Formwork Area (m^2) Allplan	Difference of Formwork Areas (m^2) Revit-Allplan	Concrete Volume (m^3) Revit	Concrete Volume (m^3) Allplan	Difference of Concrete Volumes (m^3) Revit-Allplan
3rd Floor	K5051	14.02	13.82	0.20	2.94	2.94	0.00
3rd Floor	K5052	14.02	13.82	0.20	2.94	2.94	0.00
3rd Floor	K5053	1.65	3.18	-1.53	0.62	0.62	0.00
3rd Floor	K5069	5.59	5.19	0.40	1.22	1.22	0.00
3rd Floor	K5076	5.84	5.44	0.40	1.28	1.28	0.00
3rd Floor	K5079	2.57	2.47	0.09	0.57	0.57	0.00
3rd Floor	K5085	6.37	6.29	0.08	1.40	1.40	0.00
3rd Floor	K5087	2.98	2.95	0.04	0.58	0.58	0.00
Roof	K6001	1.55	3.08	-1.53	0.62	0.62	0.00
Roof	K6006	2.67	3.08	-0.41	0.62	0.62	0.00
Roof	K6007	13.35	11.86	1.49	2.34	2.34	0.00
	Total	**5762.44**	**5888.31**	**-125.87**	**1279.32**	**1277.67**	**1.65**
Ratio of Difference (%) (Revit - Allplan)		**-2.14%**			**0.13%**		

Modeling mistakes in Allplan results from missing shaft openings in floors, incorrect floor thicknesses, and incorrect level of beams. Figure 4.6 shows an example of modeling mistake in Allplan due to missing a shaft opening on the floor. As it is seen, there is shaft openings at the same place in lower and upper floors. When the shaft opening is modeled, formwork area of beam K2080 increases by 0.12 m^2 and formwork area of beam K2155A increases by 0.58 m^2 reaching the correct values. Figure 4.12 shows an example of modeling mistake in Allplan due to the incorrect floor thickness. Floor thickness of D314 floor is modeled as 15 cm in Allplan model however the real thickness of the floor is 20 cm. Figure 4.13 shows an example of modeling mistake in Allplan due to incorrect level of beam. The level of K1004 beam needs to be the same with K1003 beam however beam is not modeled at the correct level. Therefore, formwork area of the beam as well as related column, structural wall, and floor are calculated wrong.

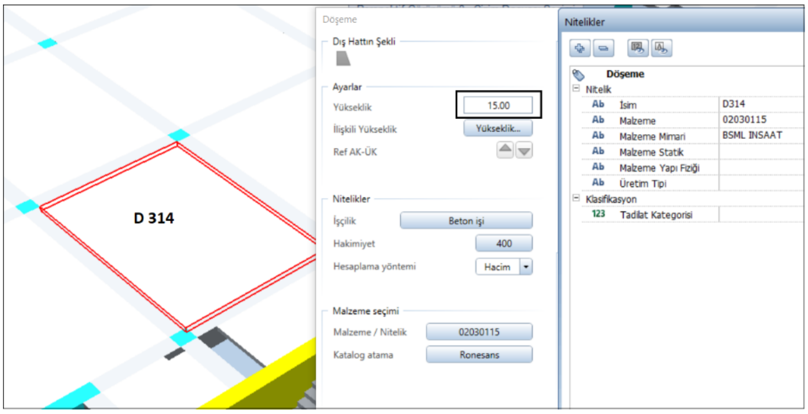

Figure 4.12. Incorrect Floor Thickness in Allplan Model

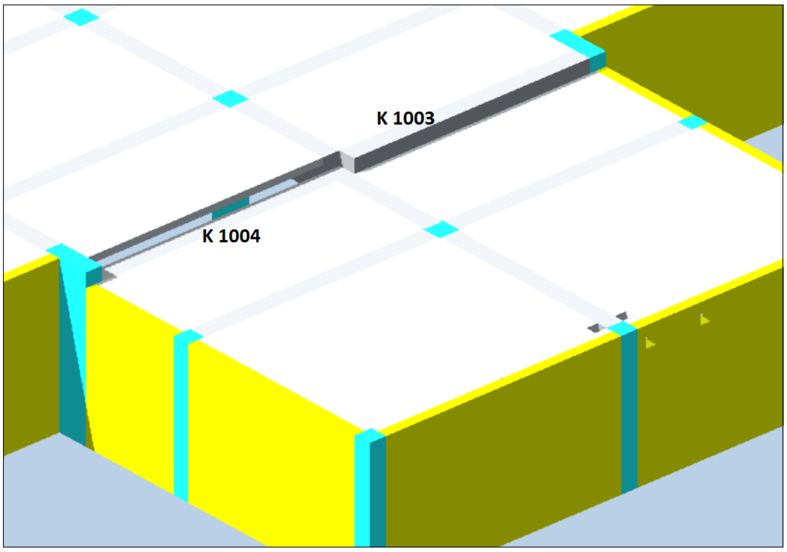

Figure 4.13. Incorrect Floor Level in Allplan Model

The formwork area errors in Revit model are originated from add-in software. When the floor at one side of the beam is lower or when there is a shaft opening in one side of the beam, the tool may give wrong results. When beam is joining with structural wall or another beam instead of columns, the tool sometimes give wrong results. Figure 4.14 shows an example of beam having shaft opening at one side. Formwork area of beam K1048 is calculated as 2.61 m^2 by the tool. The correct formwork area is 5.16 m^2. Tool is calculating bottom formwork area correctly however formwork area of the sides are incorrect. Figure 4.15 shows an example of beam joining with structural wall at the facade of the building. Formwork area of beam K2008 is calculated as 1.648 m^2 by the tool however correct formwork area is 3.178 m^2. Formwork area of bottom face is calculated correctly but sides are incorrect.

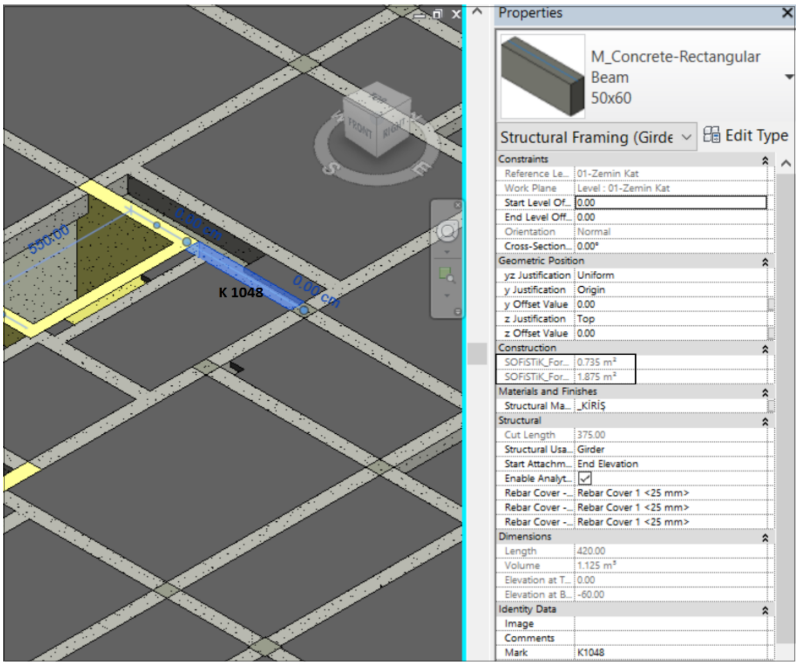

Figure 4.14. Beam Having Shaft Opening at One Side in Revit Model

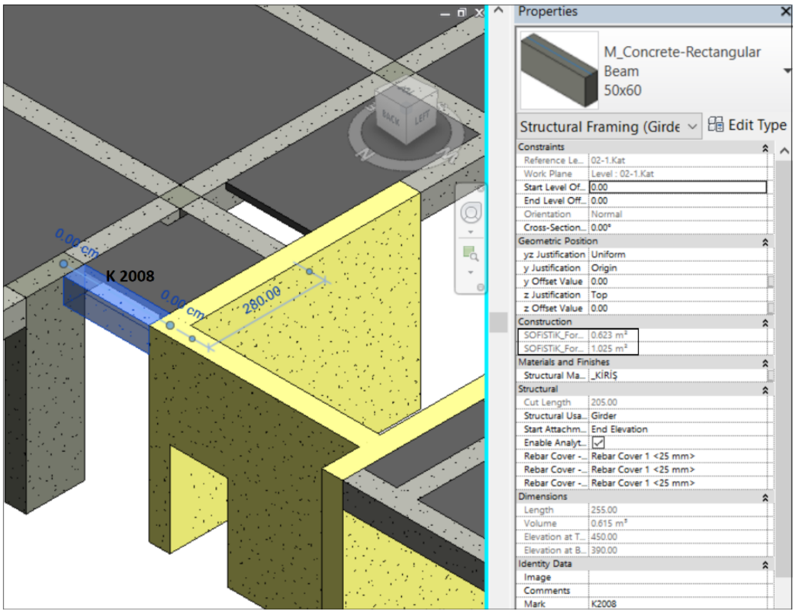

Figure 4.15. Beam Joining with Structural Wall in Revit Model

With regard to Table 4.4, there are differences in concrete volume of 2 beams. The reasons of differences in concrete volume quantities are examined and it is observed that all of the differences are originated from modeling mistakes in Allplan model.

To sum up, total formwork area of beams in Revit model is 125.87 m^2 less than Allplan model and the ratio of difference is -2.14%. Also, the concrete volume of the beams in Revit model is 1.65 m^3 more than Allplan model and the ratio of difference is 0.13%. When the differences are analyzed, it is seen that the major difference in formwork area quantities arises from calculation errors of formwork area tool in Revit. After modeling mistakes are rectified, the ratio of the difference in formwork area nearly same. Therefore, in order to rely on the results obtained from formwork area tool, it seems that there is a need for an updated tool to prevent such errors. The reason of the difference in concrete volume is due to modeling mistakes and if the human errors are rectified, there is no difference in quantities. Eventually, concrete volumes obtained from both BIM models and formwork area obtained from Allplan model are accurate and can be practically used but formwork areas obtained from Revit model needs to be checked and verified during the execution of the project.

4.1.5. Comparison of Floor Quantity Take-off

Formwork area and concrete volume of floors are extracted from Revit and Allplan models and then a comparison table which shows the quantities and their differences is generated. Floors are named according to the numbers written on the project drawings and by this way comparison could be carried out for each floor separately. Some floor numbers are not included in Allplan model and therefore formwork area and concrete volume of unspecified floors are written at the end of the comparison table. Table 4.5 includes information regarding level of floors, floor names, quantities, difference of quantities, and ratio of total differences. The table shows only floors having different quantities. There are 391 floor pieces in the building and only floors having different quantities are examined and checked by manual calculations.

As it is seen in comparison table, there are differences in the formwork area of 68 floors. The reasons of differences in formwork areas are examined and it is observed that 64 of the differences arise from formwork area tool errors in Revit and 4 of the differences arise from both formwork area tool errors in Revit and modeling mistakes in Allplan model.

Table 4.5. *Floors with Different Formwork Area and/or Concrete*

Level	Floor Name	Formwork Area (m^2) Revit	Formwork Area (m^2) Allplan	Difference of Formwork Areas (m^2) Revit-Allplan	Concrete Volume (m^3) Revit	Concrete Volume (m^3) Allplan	Difference of Concrete Volumes (m^3) Revit-Allplan
Basement	D104	42.92	43.12	-0.20	8.59	8.59	0.00
Basement	D105	42.92	43.12	-0.20	8.59	8.59	0.00
Basement	D111	42.92	43.03	-0.10	8.59	8.59	0.00
Basement	D118	41.11	41.70	-0.59	8.22	8.22	0.00
Basement	D123	8.30	8.61	-0.31	1.25	1.25	0.00
Basement	D124	8.30	8.61	-0.31	1.25	1.25	0.00
Basement	D125	41.78	41.98	-0.20	8.36	8.36	0.00
Basement	D127	40.33	40.55	-0.22	8.07	8.07	0.00
Basement	D138	20.06	20.47	-0.41	3.41	3.41	0.00
Basement	D142	16.90	17.05	-0.15	2.87	2.87	0.00
Basement	D162	16.93	17.07	-0.15	2.88	2.88	0.00
Basement	D165	40.36	40.49	-0.13	8.07	8.07	0.00
Basement	D167	39.59	39.97	-0.38	7.92	7.92	0.00
Basement	D178	40.36	40.51	-0.15	8.07	8.07	0.00
Basement	D184	4.31	4.41	-0.11	0.65	0.65	0.00
Basement	D186	46.40	46.54	-0.14	9.28	9.28	0.00
Basement	D188	40.36	40.49	-0.13	8.07	8.07	0.00
Basement	D189	40.36	40.49	-0.13	8.07	8.07	0.00
Ground Floor	D201	40.37	40.50	-0.13	8.07	8.07	0.00
Ground Floor	D202	40.37	40.50	-0.13	8.07	8.07	0.00
Ground Floor	D205	40.37	40.50	-0.13	8.07	8.07	0.00
Ground Floor	D209	4.62	4.72	-0.11	0.69	0.69	0.00
Ground Floor	D210	4.62	4.72	-0.11	0.69	0.69	0.00
Ground Floor	D211	39.97	40.56	-0.59	7.99	7.99	0.00
Ground Floor	D216	8.30	8.61	-0.31	1.25	1.25	0.00

Table 4.5. *Floors with Different Formwork Area and/or Concrete*

Level	Floor Name	Formwork Area (m^2) Revit	Formwork Area (m^2) Allplan	Difference of Formwork Areas (m^2) Revit-Allplan	Concrete Volume (m^3) Revit	Concrete Volume (m^3) Allplan	Difference of Concrete Volumes (m^3) Revit-Allplan
Ground Floor	D217	8.30	8.61	-0.31	1.25	1.25	0.00
Ground Floor	D218	40.37	40.50	-0.13	8.07	8.07	0.00
Ground Floor	D220	40.33	40.55	-0.22	8.07	8.07	0.00
Ground Floor	D229	3.71	3.96	-0.25	0.56	0.56	0.00
Ground Floor	D234	16.90	17.05	-0.15	2.87	2.87	0.00
Ground Floor	D245	16.93	17.07	-0.15	2.88	2.88	0.00
Ground Floor	D247	40.37	40.50	-0.13	8.07	8.07	0.00
Ground Floor	D249	39.59	39.97	-0.38	7.92	7.92	0.00
Ground Floor	D261	40.37	40.50	-0.13	8.07	8.07	0.00
Ground Floor	D268	4.31	4.45	-0.14	0.65	0.86	-0.22
Ground Floor	D270	46.41	46.55	-0.14	9.28	9.28	0.00
Ground Floor	D272	40.37	40.50	-0.13	8.07	8.07	0.00
Ground Floor	D273	40.37	40.50	-0.13	8.07	8.07	0.00
1st Floor	D301	40.37	40.50	-0.13	8.07	8.07	0.00
1st Floor	D302	40.37	40.50	-0.13	8.07	8.07	0.00
1st Floor	D305	40.37	40.50	-0.13	8.07	8.07	0.00
1st Floor	D309	4.62	4.72	-0.11	0.69	0.69	0.00
1st Floor	D310	4.62	4.72	-0.11	0.69	0.69	0.00
1st Floor	D314	33.02	33.02	0.00	6.60	4.95	1.65
1st Floor	D315	33.02	33.02	0.00	6.60	4.95	1.65
1st Floor	D316	8.30	8.61	-0.31	1.25	1.25	0.00
1st Floor	D317	8.30	8.61	-0.31	1.25	1.25	0.00
1st Floor	D318	40.37	40.50	-0.13	8.07	8.07	0.00
1st Floor	D320	40.33	40.55	-0.22	8.07	8.07	0.00
1st Floor	D329	3.71	3.96	-0.25	0.56	0.56	0.00

Table 4.5. *Floors with Different Formwork Area and/or Concrete*

Level	Floor Name	Formwork Area (m^2) Revit	Formwork Area (m^2) Allplan	Difference of Formwork Areas (m^2) Revit-Allplan	Concrete Volume (m^3) Revit	Concrete Volume (m^3) Allplan	Difference of Concrete Volumes (m^3) Revit-Allplan
1st Floor	D346	18.61	18.83	-0.22	3.72	3.72	0.00
1st Floor	D350	40.37	40.50	-0.13	8.07	8.07	0.00
1st Floor	D352	39.59	39.97	-0.38	7.92	7.92	0.00
1st Floor	D364	40.37	40.50	-0.13	8.07	8.07	0.00
1st Floor	D371	4.31	4.41	-0.11	0.65	0.65	0.00
1st Floor	D373	46.41	46.55	-0.14	9.28	9.28	0.00
1st Floor	D375	40.37	40.50	-0.13	8.07	8.07	0.00
1st Floor	D376	40.37	40.50	-0.13	8.07	8.07	0.00
2nd Floor	D415	8.30	8.61	-0.31	1.25	1.25	0.00
2nd Floor	D416	8.30	8.61	-0.31	1.25	1.25	0.00
2nd Floor	D420	21.30	21.30	0.00	3.62	4.26	-0.64
2nd Floor	D431E	7.23	7.82	-0.59	1.45	1.45	0.00
2nd Floor	D445	18.59	18.82	-0.23	3.72	3.72	0.00
2nd Floor	D465	40.14	40.48	-0.34	8.03	8.03	0.00
2nd Floor	D471	46.41	46.55	-0.14	9.28	9.28	0.00
3rd Floor	D509	8.30	8.65	-0.35	1.25	1.41	-0.17
3rd Floor	D519	20.48	20.82	-0.35	3.48	3.48	0.00
3rd Floor	D532E	7.01	7.86	-0.85	1.19	1.19	0.00
3rd Floor	D539	27.16	27.60	-0.44	5.43	5.43	0.00
3rd Floor	D544	4.56	4.56	0.00	0.68	0.91	-0.23
3rd Floor	D545	6.09	6.25	-0.16	1.22	1.22	0.00
Various	Unspecified	0.00	20.68	-20.68	0.00	0.00	0.00
	Total	**9978.97**	**10014.78**	**-35.81**	**1922.89**	**1920.84**	**2.05**
Ratio of Difference (%) (Revit - Allplan)		**-0.36%**			**0.11%**		

Modeling mistakes in Allplan result from missing shaft openings in floors or incorrect floor thicknesses. These modeling mistakes have small impact on the formwork area. Floor thickness error affects the side formwork area of a floor when there is a shaft opening. Figure 4.6 shows an example of modeling mistake in Allplan due to a missing shaft opening on the floor. There should be a shaft opening on the floor and when the shaft opening is modeled, formwork area of the sides increase by 0.12 m^2. Figure 4.16 shows an example of modeling mistake in Allplan due to incorrect floor thickness of floor D268. Floor thickness of the floor is modeled as 20 cm however correct floor thickness is 15 cm. Since there is a shaft opening in the floor, formwork area of the sides are calculated wrong. When the thickness of the floor is corrected, the formwork area of sides decreases by 0,035 m^2.

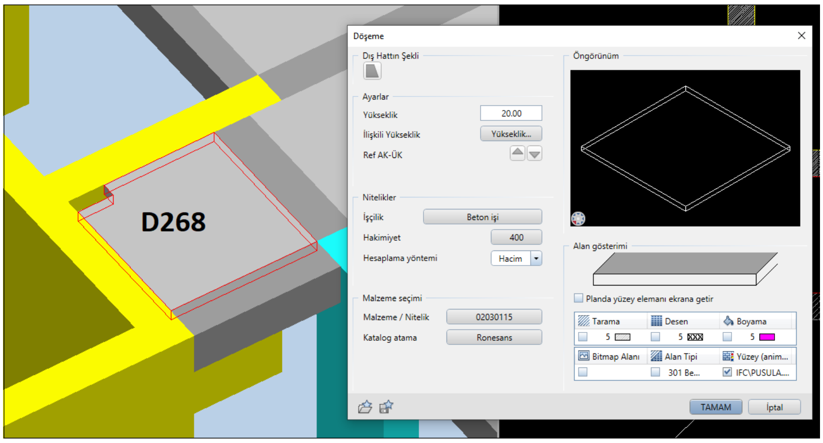

Figure 4.16. Incorrect Floor Thickness in D268 Floor in Allplan Model

Formwork area errors in Revit model are originated from add-in software. Formwork area tool gives areas of the bottom and sides separately. For this model, tool gives negative side formwork area for most of the floors, therefore side formwork areas cannot be taken into account directly. All of the side formwork areas obtained from

Revit model are controlled and only the accurate ones are added to the total formwork area.

When there is a shaft opening in the floor, formwork area of the floor is calculated incorrectly by the tool. It is observed that all formwork area tool errors in this model are on the floors having shaft openings. Figure 4.17 shows an example of formwork area tool error on a floor having a shaft opening. For the floor D138, side formwork area is calculated as -1.819 m^2 and bottom formwork area is calculated as 20.060 m^2. Bottom formwork area is calculated correctly. Since the formwork area of the sides are calculated as negative values, they are not taken into account. Formwork area of the sides are calculated as 0.408 m^2 by manual calculations. Therefore, the correct total formwork area of the floor is 20.468 m^2 which is also calculated as same in Allplan model.

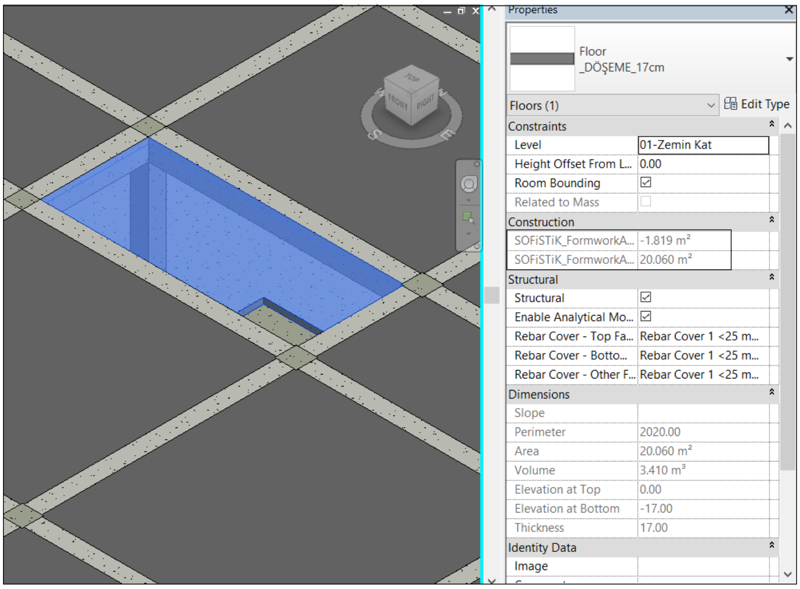

Figure 4.17. Incorrect Formwork Area of D138 Floor Having Shaft Opening in Revit Model

With respect to Table 4.5, there are differences in concrete volume of 6 floors. The reasons of differences in concrete volume quantities are investigated and it is observed that all of the differences are originated from modeling mistakes in Allplan model. All of the differences results from incorrect floor thicknesses. Figure 4.7 shows an example of incorrect modeling of floor thickness. The D314 floor is modeled as 15 cm in Allplan model however the thickness of the floor should be 20 cm. When the floor thickness is corrected, the concrete volume of the floor increases by 1.65 m^3 and the total concrete volume is adding up to correct value.

As a result, total formwork area of floors in Revit model is 35.81 m^2 less than Allplan model with a ratio of difference of -0.36% and the concrete volume of floors in Revit model is 2.05 m^3 more than Allplan model with a ratio of difference of 0.11%. The major difference in formwork area quantities arises from calculation errors of formwork area tool. Although the difference in formwork area quantities is less than 1%, the difference is considerable. The tool error may cause greater differences in different buildings. When the human errors are eliminated, difference in concrete volumes obtained from both models become zero. Eventually, concrete volumes obtained from both BIM models and formwork area quantities obtained from Allplan model are accurate and can be used reliably but formwork areas obtained from Revit model needs to be checked before using them during the execution of the project.

4.1.6. Comparison of Parapet Wall Quantity Take-off

Formwork area and concrete volume of parapet walls are extracted from Revit and Allplan models and also a comparison table which shows quantities and their differences is generated. Parapet walls are named according to the types written on the project and by this way, comparison could be carried out for each type of parapet wall on each floor. Table 4.6 includes information regarding level of parapet walls, parapet wall names, quantities, difference of quantities, and ratio of total differences. There are one type of parapet wall on 2nd floor, four types of parapet wall on 3rd floor and two types of parapet wall on roof level. Quantities of all parapet walls are analyzed and checked with manual calculations.

As it is seen in comparison table, there are differences in formwork area and concrete volume of two types of the parapet walls. The reasons of differences in formwork areas and concrete volumes are examined and it is observed that all of the differences arise from modeling mistakes in Allplan model.

Modeling mistakes in Allplan resulted from join error of parapet wall and column or incorrect level of parapet walls. These modeling mistakes have small impact on formwork area. As it is seen in Figure 4.3, there is a modeling mistake in Allplan model due to join error of parapet wall and S11 column on 3rd floor. Same error exists in the joint of S82 column and parapet walls. Parapet walls are joined inside of the columns. Therefore, formwork area and concrete volume of the parapet walls are calculated wrong. Formwork area of PR500 type of parapet walls on 3rd floor is calculated as 481.0 m^2 in Allplan model however the actual formwork area is 479.2 m^2. Concrete volume of PR500 type of parapet walls on the 3rd floor is calculated as

60.13 m^3 however the actual concrete volume is 59.9 m^3. When these errors are eliminated in Allplan model, the correct results are obtained.

To sum up, total formwork area of parapet walls in Revit model is 0.28 m^2 less than Allplan model with a ratio of difference of -0.02%. Similarly, the concrete volume of parapet walls in Revit model is 0.08 m^3 less than Allplan model with a ratio of difference of -0.05%. When all human errors are corrected, difference in quantities becomes zero. Consequently, concrete volumes and formwork areas obtained from both BIM models are accurate and can be reliably used.

Table 4.6. *Comparison of Formwork Area and Concrete Volume of Parapet Walls*

Level	Parapet Wall Name	Formwork Area (m2) Revit	Formwork Area (m2) Allplan	Difference of Formwork Areas (m2) Revit-Allplan	Concrete Volume (m3) Revit	Concrete Volume (m3) Allplan	Difference of Concrete Volumes (m3) Revit-Allplan
3rd Floor	PR400	585.92	585.92	0.00	58.58	58.58	0.00
Roof	PR500	479.20	481.00	-1.80	59.90	60.13	-0.23
Roof	PR600	7.68	7.68	0.00	1.92	1.92	0.00
Roof	PR700	59.29	57.77	1.52	5.54	5.39	0.15
Roof	PR800	42.91	42.91	0.00	4.29	4.29	0.00
Above Roof	PR600	91.42	91.42	0.00	9.14	9.14	0.00
Above Roof	PR700	21.76	21.76	0.00	2.18	2.18	0.00
	Total	**1288.17**	**1288.45**	**-0.28**	**141.55**	**141.63**	**-0.08**
Ratio of Difference (%) (Revit - Allplan)			**-0.02%**			**-0.05%**	

4.1.7. Comparison of Vertical and Horizontal Beam Quantity Take-off

Length of vertical and horizontal beams are extracted from Revit and Allplan models and also a comparison table which shows the quantities and their differences is generated as well. Since there is no markings on the project drawings for vertical and horizontal beams, comparison could be carried out for each floor. Table 4.7 and Table 4.8 includes information regarding level of beams, length of beams, difference between lengths, and ratio of total differences for vertical and horizontal beams, respectively. In order to figure out the reasons of differences, the length of some beams are reviewed and manual calculation is carried out only for these elements.

As it is seen in Table 4.7, there are differences in the length of vertical beams on ground floor, 1st floor and roof. When Table 4.8 is reviewed, it is seen that there are differences in the length of horizontal beams at basement, 1st floor, 3rd floor, and roof. The reasons of differences in the length of vertical and horizontal beams are examined and it is observed that all of the differences arise from modeling mistakes in Allplan model.

Table 4.7. *Comparison of Length of Vertical Beams*

Level	Length of Vertical Beams (m) Revit	Length of Vertical Beams (m) Allplan	Difference of Lengths (m) Revit-Allplan
Basement	58.10	58.10	0.00
Ground Floor	117.80	117.00	0.80
1st Floor	121.90	120.90	1.00
2nd Floor	129.30	129.30	0.00
3rd Floor	53.40	53.40	0.00
Roof	14.67	15.40	-0.73
Total	**495.17**	**494.10**	**1.07**
Ratio of Difference (%) (Revit - Allplan)	**0.22%**		

Table 4.8. *Comparison of Length of Horizontal Beams*

Level	Length of Horizontal Beams (m) Revit	Length of Horizontal Beams (m) Allplan	Difference of Lengths (m) Revit-Allplan
Basement	161.19	160.57	0.63
Ground Floor	341.00	341.00	0.00
1st Floor	410.80	411.45	-0.65
2nd Floor	389.20	389.20	0.00
3rd Floor	184.82	184.55	0.27
Roof	29.63	32.74	-3.11
Total	**1516.64**	**1519.51**	**-2.87**
Ratio of Difference (%) (Revit - Allplan)	**-0.19%**		

Modeling mistakes in Allplan results from incorrect level of vertical beams, join error of vertical beams, and incorrect length of horizontal beams. Figure 4.18 shows an example of incorrect level of vertical beam. There are 4 vertical beams located on 1st floor and there is a low floor at the location of these vertical beams. Since the low floor is overlooked during modeling, the height of beams are modeled 25 cm shorter than their actual height. Figure 4.19 shows an example of incorrect level of vertical beams and improper join of horizontal and vertical beams. There is the structural wall with 27 cm top offset and the parapet wall with 33 cm top offset. Since these offsets were not taken into account, height of these vertical beams are modeled higher than their real height in Allplan model. Joint of vertical and horizontal beams is also improper as seen in Figure 4.19. Horizontal beams are joined inside of the vertical beam therefore the length of horizontal beams are incorrect. Figure 4.20 shows an example of incorrect length of horizontal beam. There is a headwall on the wall whose location is shown in figure. Since the headwall is not considered, vertical beam is modeled behind the headwall. Therefore, the length of horizontal beam is higher than its real values. When these errors are eliminated in Allplan model, the correct results are obtained.

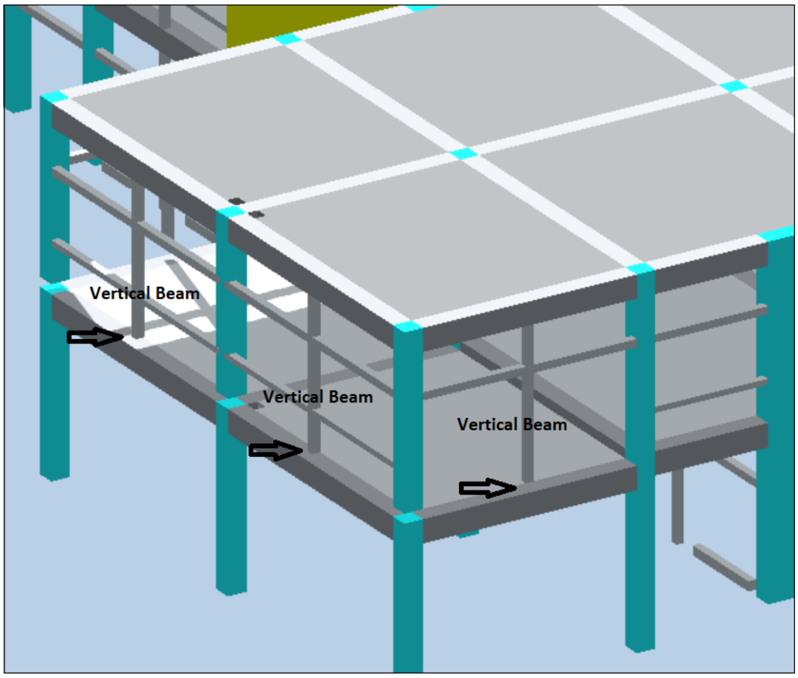

Figure 4.18. Incorrect Height of Vertical Beams in Allplan Model

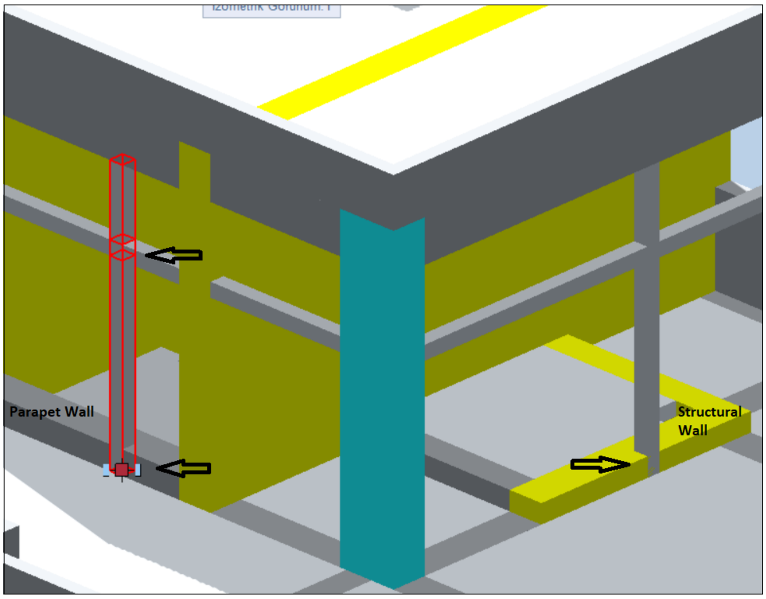

Figure 4.19. Incorrect Level of Vertical Beams and Improper Joint of Beams in Allplan Model

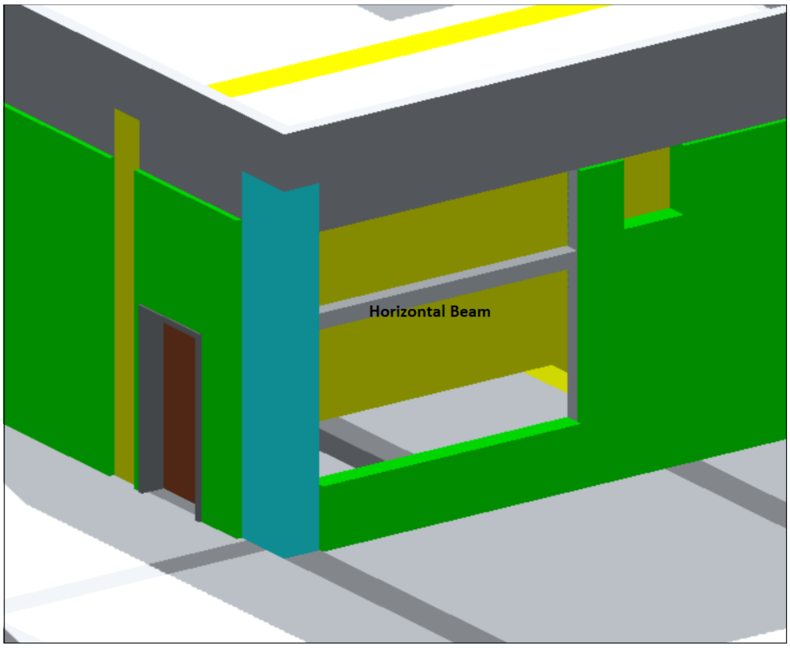

Figure 4.20. Incorrect Length of Horizontal Beam in Allplan Model

Apart from the noted issues, one of the situation faced with during modeling vertical and horizontal beams in Revit is that it is possible to model two beams just at the same location. Therefore, the length of beam is extracted as twice however formwork area and concrete volume of the second beam is calculated as zero. Since the length of vertical and horizontal beams are needed for the comparison, these errors have to be avoided. Figure 4.21 shows an example of horizontal beam modeled over the other horizontal beam. These type of errors are detected and eliminated before comparing quantities of beams.

Furthermore, there are two type of lengths calculated by Revit for the beams. One of them is length and the other one is cut length. Length vary according to the modeling approach which means that it is the length between points chosen while modeling beam. If points are chosen from center of columns, the length is measured from center of column to center of column. On the contrary, cut length is the actual length of beam which means that it is free from the points chosen while modeling. Figure 4.22 shows an example of beam having unequal length and cut length. Cut length of beams are taken into account during comparison.

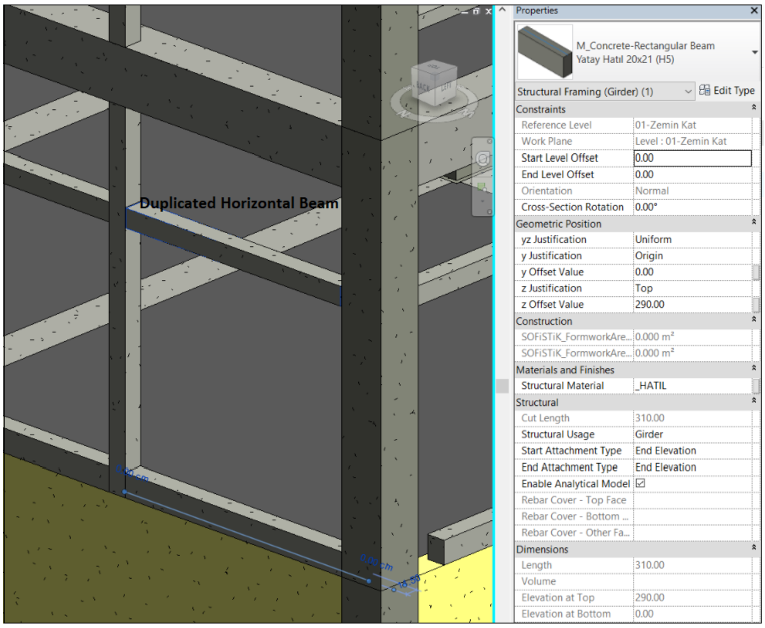

Figure 4.21. Duplicated Horizontal Beam in Revit Model

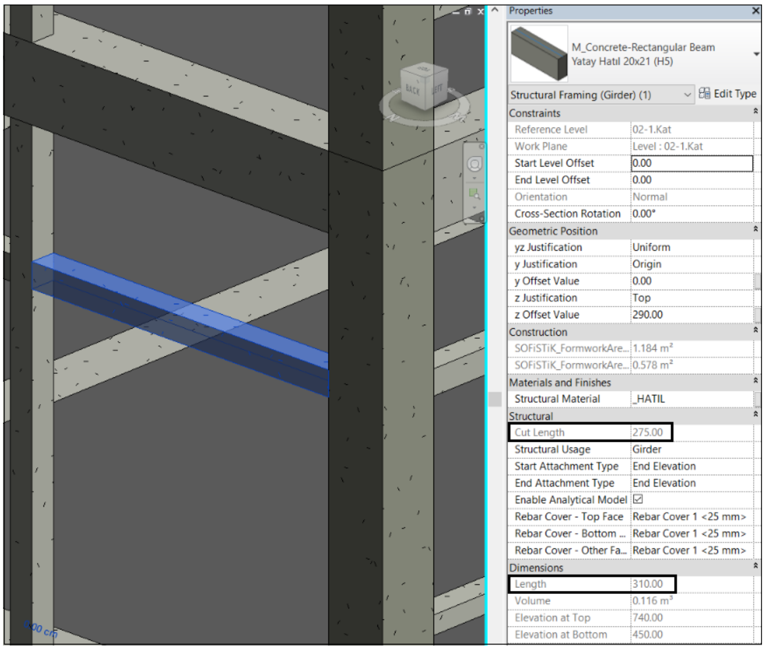

Figure 4.22. Beam having Unequal Length and Cut Length

To sum up, total length of vertical beams in Revit model is 1.07 m more than Allplan model and the ratio of difference is 0.22%. Similarly, total length of horizontal beams in Revit model is 2.87 m less than Allplan model and the ratio of difference is -0.19%. It can be concluded when all modeling mistakes are rectified there is no difference in quantities. Eventually, length of vertical and horizontal beam obtained from both BIM models are accurate and can be used reliably.

4.1.8. Comparison of Vertical and Horizontal Beam Quantity Take-off

Area of exterior architectural walls are extracted from Revit and Allplan models and also a comparison table which shows the quantities and their differences is generated. Since there is no markings on the project drawings for the architectural walls, comparison could be carried out according to the total wall area at each floor. Table 4.9 includes information regarding level of exterior walls, area of walls, difference between areas, and ratio of total differences. In order to figure out the reasons of differences, area of some walls are investigated and manual calculation is carried out only for these walls.

Table 4.9. *Comparison of Exterior Architectural Wall Areas*

Level	Area of Exterior Wall (m^2) Revit	Area of Exterior Wall (m^2) Allplan	Difference of Areas (m^2) Revit-Allplan
Basement	338.64	341.57	-2.93
Ground Floor	509.32	502.02	7.30
1st Floor	655.36	648.74	6.62
2nd Floor	776.48	768.85	7.62
3rd Floor	272.06	262.45	9.61
Roof	83.74	88.18	-4.43
Total	**2635.60**	**2611.82**	**23.78**
Ratio of Difference (%) (Revit - Allplan)	**0.91%**		

As it is seen in Table 4.9, there are differences in the area of exterior architectural wall at each floor. The reasons of differences in areas of exterior architectural walls are examined and it is estimated that all differences results from modeling mistakes in Allplan and Revit models. Exterior walls were modeled like there are no vertical and horizontal beams in Allplan model and vertical and horizontal beams were modeled in another model file. In order to reach the area of exterior architectural wall, area of the vertical and horizontal beams reserving a place on facade is subtracted from the area of the architectural walls. On the contrary, exterior walls are modeled after modeling vertical and horizontal beams and they are placed between beams in Revit model. Therefore, comparison cannot be made for each wall separately due to different modeling approaches.

Figure 4.23 shows a view of the building after modeling exterior architectural walls. As it is seen from the figure that the exterior walls are modeled with exterior faces being 7 cm outside of the structural framework.

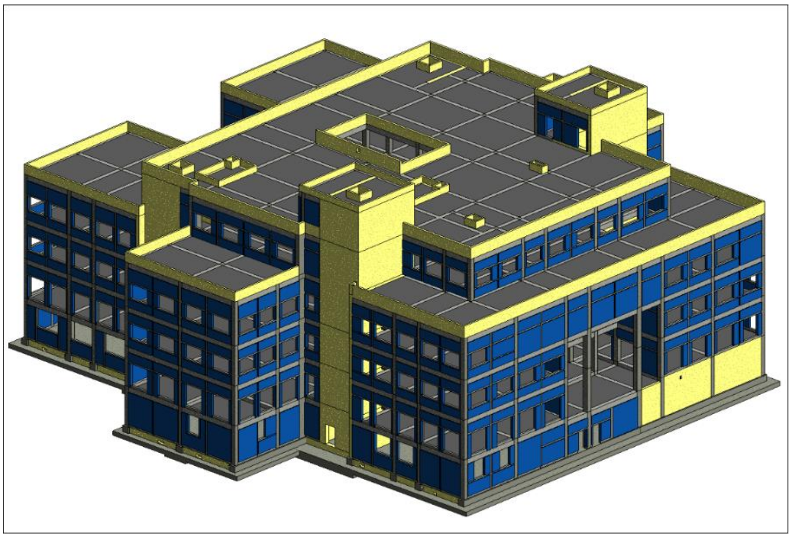

Figure 4.23. View of Building after modeling Exterior Walls

To sum up, total area of exterior architectural walls in Revit model is 23.78 m^2 more than Allplan model and the ratio of difference is 0.91%. Since the difference in quantities is due modeling mistakes and less than 1.00%, and also it has very little impact on the cost of the project, the quantities are accepted as reliable As a result, area of exterior architectural walls obtained from Allplan and Revit models are accurate and can be used reliably during the execution of the project.

4.1.9. Comparison of Vertical and Horizontal Beam Quantity Take-off

Area of facade insulations are extracted from Revit and Allplan models and also a comparison table which shows the quantities and their differences is generated. Since there is no markings on the project drawings for the facade insulations, comparison could be carried out according to the total insulation area at each floor. Table 4.10 includes information regarding level of insulation, area of insulation, difference between areas, and ratio of total differences. In order to figure out the reasons of differences, area of some insulation elements are examined and manual calculation is carried out only for these insulation elements.

Table 4.10. *Comparison of Facade Insulation Areas*

Level	**Area of Facade Insulation (m^2) Revit**	**Area of Facade Insulation (m^2) Allplan**	**Difference of Areas (m^2) Revit-Allplan**
Basement	251.92	247.39	4.54
Ground Floor	583.29	561.97	21.32
1st Floor	527.77	520.72	7.04
2nd Floor	504.39	801.37	-296.98
3rd Floor	712.11	644.47	67.64
Roof	523.48	282.49	240.99
Total	**3102.95**	**3058.41**	**44.55**
Ratio of Difference (%) (Revit - Allplan)	**1.46%**		

As it is seen in Table 4.10, there are differences in the area of facade insulations in each floor. The reasons of the differences are examined and it is seen that some of the differences results from modeling mistakes in Allplan model. For instance, facade insulation of S48 and S58 columns located on ground floor were not modeled in Allplan. Total area of these forgotten insulation elements is 23.52 m^2. Figure 4.24 shows view of S58 column whose facade insulation is not modeled. The remaining difference is accepted as arising from modeling mistakes in both Allplan and Revit models.

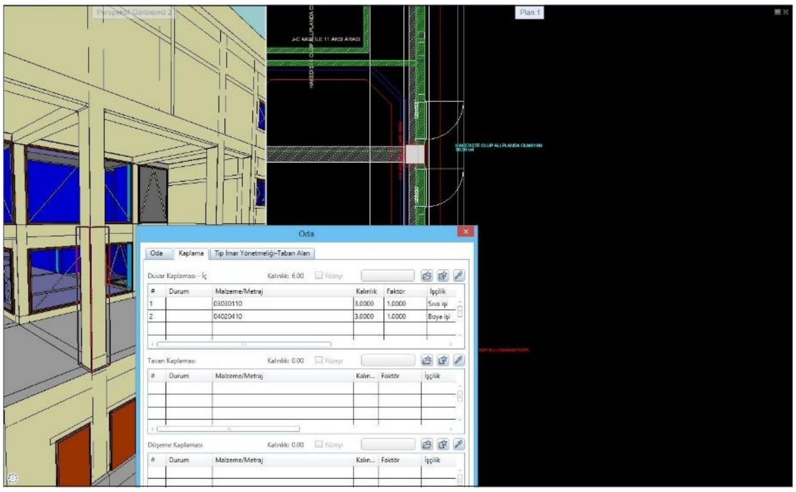

Figure 4.24. S58 Column at Ground Floor in Allplan Model

When Table 4.10 is considered, it is seen that the quantities are very different in some levels of building. This situation results from difference in modeling approaches of BIM programs. In Allplan, facade insulation is modeled by covering selected areas in the model. Since parapet walls are the continuation of the lower floor, parapet walls are accepted as a part of the lower floor in Allplan. In Revit, belonging floor of the elements are evaluated only according to their real level. Therefore, there are differences on some levels due to various modeling approaches of BIM programs.

In Conclusion, the total area of facade insulation in Revit model is 44.55 m^2 more than Allplan model and the ratio of difference is 1.46%. When all human errors are rectified, there is no difference in the quantities and therefore it can be said that difference is negligible. Besides, the difference has very little impact on cost of the project. Eventually, quantities obtained from both BIM model are accurate and can be used confidingly for the projects.

4.1.10. Comparison of Vertical and Horizontal Beam Quantity Take-off

Area of plastering and painting are extracted from Revit and Allplan models and also a comparison table which shows quantities and their differences is generated. Since there is no markings on the project drawings for exterior coating elements, comparison could be carried according to the total areas at each floor. Table 4.11 and Table 4.12 includes information regarding level of coating elements, area of coating elements, difference between areas, and ratio of total differences. In order to figure out the reasons of differences, area of some coating elements are studied and manual calculation is carried out only for these elements.

As it is seen in Table 4.11 and Table 4.12, there are differences in area of plastering and painting elements at each floor. The reasons of differences in areas of exterior coatings are examined and it is estimated that the differences results from modeling mistakes in both Allplan and Revit models.

When Table 4.11 and 4.12 are examined, it is seen that the quantities have major differences on some levels of building. This situation results from difference in modeling approaches of BIM programs. In Allplan, coatings are modeled by selecting areas in the model. When some facade areas are selected with the areas actually belonging below or above floor, these areas are also accepted as existing at those levels. Therefore, there are differences in some levels due to various modeling approaches of the BIM programs.

Table 4.11. *Comparison of Exterior Plastering Areas*

Level	Area of Exterior Plastering (m^2) Revit	Area of Exterior Plastering (m^2) Allplan	Difference of Areas (m^2) Revit-Allplan
Basement	590.56	465.18	125.39
Ground Floor	1092.61	1145.76	-53.15
1st Floor	1183.12	1187.79	-4.67
2nd Floor	1280.86	1596.91	-316.05
3rd Floor	984.17	878.28	105.88
Roof	50759	332.02	175.57
Total	**5638,91**	**5605.94**	**32.98**
Ratio of Difference (%) (Revit - Allplan)	**0.59%**		

Table 4.12. *Comparison of Exterior Painting Areas*

Level	Area of Exterior Painting (m^2) Revit	Area of Exterior Painting (m^2) Allplan	Difference of Areas (m^2) Revit-Allplan
Basement	590.56	465.18	125.39
Ground Floor	1092.61	1145.76	-53.15
1st Floor	1183.12	1187.79	-4.67
2nd Floor	1280.86	1596.91	-316.05
3rd Floor	984.17	878.28	105.88
Roof	507.59	332.02	175.57
Total	**5638.91**	**5605.94**	**32.98**
Ratio of Difference (%) (Revit - Allplan)	**0.59%**		

Consequently, total area of both exterior plastering and painting in Revit model is 32.98 m^2 more than Allplan model and the ratio of difference is 0.59%. Since the difference in the area of exterior plastering and painting is less than 1.00% and has very little impact on cost of the project it can be accepted that the difference is negligible. As a result, obtained quantities for exterior plastering and painting are accurate and can be confidingly used.

4.1.11. Comparison of Vertical and Horizontal Beam Quantity Take-off

Number of exterior windows, headwalls and area of curtain walls are extracted from Revit and Allplan models and also a comparison table which shows quantities and their differences is generated. Windows, headwalls and curtain walls were named according to their types written on the project drawings. Therefore, comparison could be carried out for each type. Table 4.13 and Table 4.14 and Table 4.15 includes information regarding type of windows/headwalls/curtain walls, number/area of elements, difference between numbers/areas, and ratio of total differences. In order to figure out the reasons of differences, area of some curtain walls are examined and manual calculation is carried out only for these elements.

As it is seen in Table 4.13 and Table 4.14, there is no difference between the number of windows and headwalls. However, as it is seen in Table 4.15, there are differences only in the area of curtain walls. The reasons of differences in areas of curtain walls are examined and it is estimated that the differences results from modeling mistakes in both Allplan and Revit models.

Table 4.13. *Comparison of Exterior Window Numbers*

Type of Window	Number of Windows Revit	Number of Windows Allplan	Difference of Number Revit-Allplan
P1 (120X245)	5.00	5.00	0.00
P1' (120X245)	4.00	4.00	0.00
P2 (240X160)	56.00	56.00	0.00
P2' (240X160)	54.00	54.00	0.00
P3' (180X245)	2.00	2.00	0.00
P4 (120X160)	13.00	13.00	0.00
P4' (120X160)	10.00	10.00	0.00
P5 (240X245)	17.00	17.00	0.00
P5' (240X245)	17.00	17.00	0.00
P6 (180X160)	2.00	2.00	0.00
P6' (180X160)	2.00	2.00	0.00
Total	**182.00**	**182.00**	**0.00**
Ratio of Difference (%) (Revit - Allplan)	**0.00%**		

Table 4.14. *Comparison of Exterior Headwalls Numbers*

Type of Headwall	Number of Headwall Revit	Number of Headwall Allplan	Difference of Number Revit-Allplan
M1 (224,5 x 207,5)	4.00	4.00	0.00
M11 (134 x 310)	1.00	1.00	0.00
M12 (362.5 x 310)	1.00	1.00	0.00
M2 (159,5 x 207,5)	4.00	4.00	0.00
M3 (264,5 x 207,5)	1.00	1.00	0.00
M4 (300 x 207,5)	1.00	1.00	0.00
M5 (109,5 x 207,5)	1.00	1.00	0.00
M6 (424,5 x 207,5)	1.00	1.00	0.00
M7 (250,5 x 207,5)	1.00	1.00	0.00
M8 (84,5 x 84,5)	1.00	1.00	0.00
Total	**16.00**	**16.00**	**0.00**
Ratio of Difference (%) (Revit - Allplan)	**0.00%**		

Table 4.15. *Comparison of Curtain Wall Areas*

Type of Curtain Wall	Area of Curtain Wall (m^2) Revit	Area of Curtain Wall (m^2) Allplan	Difference of Areas (m^2) Revit-Allplan
ACD 1	7.56	7.59	-0.03
ACD 2	63.12	64.05	-0.93
ACD 3	10.75	10.46	0.29
GC 1	159.36	157.70	1.66
GC 2	74.49	74.80	-0.31
GC 3	36.90	36.78	0.12
Total	**352.18**	**351.38**	**0.80**
Ratio of Difference (%) (Revit - Allplan)	**0.23%**		

Number of exterior doors are extracted from Revit and Allplan models and also a comparison table which shows quantities and their differences is generated. Doors were named according to their types written on the project drawings. Therefore, comparison could be carried out for each type. Table 4.16 includes information regarding type of doors, number of doors, difference between numbers, and ratio of total differences.

4.1.12. Comparison of Vertical and Horizontal Beam Quantity Take-off

Number of exterior doors are extracted from Revit and Allplan models and also a comparison table which shows quantities and their differences is generated. Doors were named according to their types written on the project drawings. Therefore, comparison could be carried out for each type. Table 4.16 includes information regarding type of doors, number of doors, difference between numbers, and ratio of total differences.

As it is seen in Table 4.16, there is no difference between the numbers of doors.

Table 4.16. *Comparison of Door Numbers*

Type of Doors	Number of Doors Revit	Number of Doors Allplan	Difference of Number Revit-Allplan
ACDK (100X237)	4.00	4.00	0.00
ACDK (120X227)	2.00	2.00	0.00
ACDK1 (160 X 270)	2.00	2.00	0.00
ACDK2 (100X237)	4.00	4.00	0.00
AKK1 (180 X 237)	2.00	2.00	0.00
AKK3 (150 X 227)	2.00	2.00	0.00
SK2 (226X227)	6.00	6.00	0.00
SK3 (126X227)	4.00	4.00	0.00
SK3 (256X273)	2.00	2.00	0.00
SK5 (140X227)	8.00	8.00	0.00
Total	**36.00**	**36.00**	**0.00**
Ratio of Difference (%) (Revit - Allplan)	**0.00%**		

As a result, there is no difference in the number of doors and it can be inferred that number of doors obtained from both BIM models are accurate and can be used reliably.

4.2. Evaluation of Revit in terms of Quantity Take-off

4.2.1. Favorable Aspects of Revit

Visual features of Revit is quite helpful while working on a model. For instance, it allows to hide or isolate the randomly selected or filtered elements in 3D view.

Therefore, position, level, or connection of elements can be checked and corrected in order to prevent errors which affects the quantity take-offs. Besides, a view created with desired elements can be saved and loaded/reviewed whenever needed.

It is possible to reach the quantities such as formwork area or wall area of elements from properties browser of Revit only by selecting the elements. This property enables to check quantities easily whenever needed.

Interface of Revit program is user-friendly. The program belongs to Autodesk and if the user is using AutoCAD for design, it is easy to adopt Revit program since user menus of these programs are quite similar.

4.2.2. Unfavorable Aspects of Revit

Structural elements are not accepted as dominating elements in Revit. For instance, even if a beam is existing above the architectural wall, height of the wall should be arranged in the properties of the wall. Program does not accept structural elements as a boundary for other elements automatically and therefore lack of this property causes extra work and make the software open to errors.

There is no way to perform measurements on the 3D view of a model in Revit. It causes extra work such as working on different plans when dimensions are desired to be observed for checking any element.

There is no formwork area tool in the Revit program. In order to obtain formwork area of the elements, an add-in which calculates formwork area needs to be installed to the software. For this study, Sofistik Bimtools add-in is used to attain formwork areas.

Revit enables to model more than one structural element at the same location. In some situations but not all, it gives warning for double modeling however it still allows to model. In Figure 4.21, an example of this situation is shown for the horizontal beams. For that horizontal beam, the length is extracted twice but formwork area and concrete volume of the second beam is calculated as zero by the tool. Therefore, there is no problem regarding the formwork area and concrete volume but the length of the beam is inaccurate. When other types of structural elements are checked for this condition, it is seen that for some elements, formwork area and/or concrete volumes are also calculated wrong. For example, when a column is modeled at the same location with another column, formwork area of both columns are calculated as negative values which is wrong, as well as concrete volumes being calculated twice. Figure 4.25 shows an example of quantities of the column modeled twice at the same location.

A	B	C	D	E	F
Level	Axle of Column	Column Size (cm)	Column Height (cm)	Concrete Volume (m3)	Formwork Area - Side (m2)
01-Zemin Kat	C-2	50x50	450	1.125 m^3	-1.089 m^2
01-Zemin Kat	C-1	50x50	450	1.125 m^3	8.306 m^2
01-Zemin Kat	C-2	50x50	450	1.125 m^3	-1.089 m^2
01-Zemin Kat	C-3	50x50	450	1.125 m^3	8.306 m^2
01-Zemin Kat	D-1	50x50	450	1.125 m^3	8.400 m^2
01-Zemin Kat	D-2	50x50	450	1.125 m^3	8.100 m^2
01-Zemin Kat	D-3	50x50	450	1.125 m^3	8.400 m^2

Figure 4.25. Quantities of Column Modeled Twice at Same Location

Quantities are extracted only as .txt file in Revit. Figure 3.26 shows the example of data in .txt format. In order to use this data for our study, data has to be transferred to Microsoft Excel and some operations are carried out to make it ready to use. This process has to be repeated when there is any change in the model. Since this process takes time and open to errors without an option to extract quantities directly into Microsoft Excel, it is one of the limitations of Revit for extracting quantities.

4.3. Evaluation of Allplan in terms of Quantity Take-off

4.3.1. Favorable Aspects of Allplan

Structural elements are accepted as dominating elements in Allplan and therefore structural elements such as beams, columns etc. are a natural boundary for other elements. For instance, when a structural element and an architectural wall overlap, Allplan automatically ignores the overlapping area of the architectural wall. Besides, when two structural elements overlap, Allplan automatically ignores one of the element's area and volume. Thus, this property avoids extra work for adjusting the boundaries of elements and prevents errors that may arise from overlapping elements.

In Allplan, a model can be opened in three different type of drawing file. First one is green drawing file which allows using all modeling functions, second one is yellow drawing file which allows only revising existing elements, and third one is gray drawing file which only allows to see elements without any changes. By the help of these drawing files, accurate quantities are obtained easily in some situations. To illustrate, if the concrete of the floor is going to be poured in parts, existing part of the concrete floors can be identified as blind mold by modeling them in another drawing file, and therefore accurate formwork quantities can be obtained.

Unlike Revit, there is a formwork area tool in Allplan program and quantities obtained from this tool are seamless.

It is possible to perform measurements on the 3D view of the model in Allplan. It prevents extra work such as working on different plans to check the dimensions of the elements under observation.

There are 3 options to extract quantities in Allplan. Quantities can be extracted to Microsoft Excel, Adobe Pdf and Microsoft Word. Especially, extracting quantities directly to Microsoft Excel is a significant advantage and accelerates the quantity take-off process. Figure 4.26 shows these three options of the Allplan software for extracting quantities.

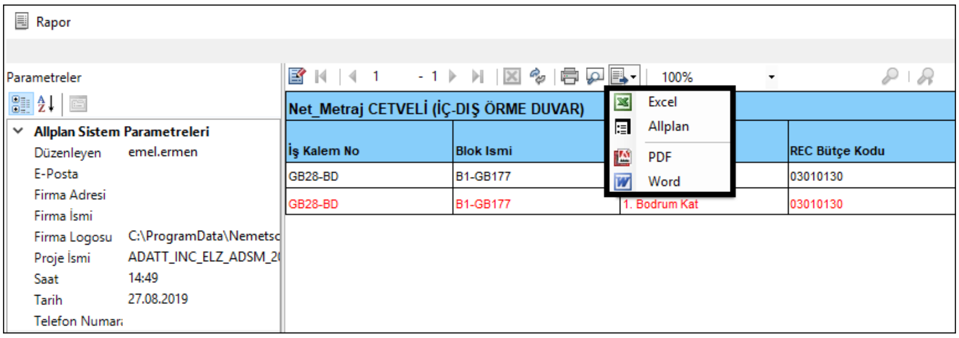

Figure 4.26. Options for Extracting Quantities in Allplan

4.3.2. Unfavorable Aspects of Allplan

Visual features of Allplan is not as advanced as Revit. There is no option to save selected views and load them again to review. It is not possible to view the quantity of elements just by selecting them in 3D view. In order to obtain the quantities of elements, quantity extraction tool needed to be run each time.

Since Autodesk AutoCAD is commonly used in construction projects to create drawings, almost all of the designers are familiar with Autodesk interfaces. Interface of Allplan is dissimilar with Autodesk's interfaces, therefore significant amount of time is required for users to learn and adapt to Allplan software.

Quantities are generally extracted for each level separately. When there is an element having relationship with elements existing in the floors below or above, there is a risk of obtaining an inaccurate quantity in Allplan. Figure 4.3 shows an example of this situation. Actually, Allplan avoids mistakes arising from overlaps due to its feature which ensures neglecting one of the overlapping element's quantities. In Allplan, parapet walls are modeled as they are part of the floor below. Since the quantities are extracted for each level separately, overlapping elements existing on different floors are considered separately and therefore the obtained quantities are wrong. To sum up, elements having connection with other elements existing on lower or upper floors need to be checked before obtaining quantities in Allplan.

CHAPTER 5

CONCLUSION

Construction projects are becoming complex and difficult to manage as time goes on and also construction industry is seeking for ways of improving processes such as quantity take-off. One of the current problems of construction industry is to obtain accurate quantities with a faster and easier method. Commonly, quantities are calculated with manual calculations by using 2D CAD drawings and CAD tools. This traditional process requires too much time and effort and also it is open to errors since almost all stages of the process are dependent to human. Today, BIM is started to being widely used to meet the requirements of the industry such as improving the processes like quantity take-off. Studies in literature show that BIM ensures benefits in terms of time and accuracy of quantities due to its automated processes. However, studies commonly concentrate on acquiring quantities in standard conditions and there is not enough research regarding challenges in obtaining quantities of some challenging construction items like formwork.

The main objective of this thesis is to evaluate the reliability of quantities extracted from 3D building information models by detecting and implementing correct modeling approaches to obtain accurate quantities. For this purpose, a case study is carried out by modeling selected construction items of a building with Autodesk Revit 2017 program and the obtained quantities are compared with the quantities extracted from Allplan 2018 model which is created by a construction company. The required approaches for each construction item to obtain accurate quantity are investigated and

QTO result of different BIM software tools are analyzed in detail. Major findings are explained in the next section. In the subsequent sections, limitations of the study are clarified and recommendations for the future studies are given.

5.1. Major Findings

Outcomes of the study can be divided into two parts. First part is about modeling approaches for construction items in order to obtain accurate quantities in Revit. Second part is about results of the comparison which is made with the obtained quantities from Revit and Allplan models.

Outcomes regarding modeling approaches for Revit are as follows:

- Since it is not possible to create a wall opening on a structural foundation element in Revit, foundation walls having openings were created as structural walls.
- In order to avoid virtual beams having no quantities in the quantity take-off list, beams should be modeled between exterior faces of vertical elements. Example of this type of beam can be seen in Figure 3.5.
- When there are vertical and/or horizontal beams existing on the facade and outer faces of exterior walls are not at the same alignment with the structural elements, the better practice is to model vertical and horizontal beams at first and then to model exterior walls piece by piece between the beams.
- Exterior layers for coating elements should be defined within the wall/insulation types before modeling so as to avoid improper joints.

- Since it is possible to model more than one structural element at the same location in Revit, attention is required while modeling structural elements to avoid incorrect measurements.
- In order to obtain accurate formwork areas, the add-in which is used to calculate formwork areas should be run for each floor separately.

Outcomes achieved from comparison of the QTO results are as follows:

- Concrete volume of all structural elements obtained from Revit and Allplan models are accurate after rectifying human errors in the models.
- Formwork area quantities of foundation elements, columns, and parapet walls are accurately obtained from Revit and Allplan models after human errors in the models are corrected.
- Formwork area of the structural walls obtained from Allplan model are accurate after human errors in the model are resolved, however quantities obtained from Revit model are inaccurate due to some errors arising from formwork area tool. Area of formwork needed for the sides of the door or window openings in the walls are not calculated by the formwork area tool. Besides, formwork areas of some structural walls are miscalculated for incomprehensible reasons.
- Formwork area of the beams obtained from Allplan model are accurate after rectifying human errors in the model however quantities obtained from Revit model are inaccurate due to some errors arising from formwork area tool.
  Formwork areas of beams are miscalculated by the tool when there is a low floor at one side of the beam or when there is a shaft opening at one side of the

beam or when beam is joining with structural wall or another beam instead of a column.

- Formwork area of floors obtained from Allplan model are accurate after correcting the human errors in the model however quantities obtained from Revit model are inaccurate due to some errors arising from formwork area tool. Formwork areas of floors are miscalculated by the tool when there is a shaft opening on the floor.
- Length of the vertical and horizontal beams obtained from Revit and Allplan models are accurate when no human errors exists in the models.
- Area of the exterior architectural walls obtained from Revit and Allplan models are accurate when no human errors exists in the models.
- Area of the facade insulation elements obtained from Revit and Allplan models are accurate when no human errors exists in the models.
- Areas of exterior plastering and exterior painting obtained from Revit and Allplan models are accurate when no human errors exists in the models.
- Number of exterior windows, headwalls, and areas of curtain walls obtained from Revit and Allplan models are accurate.
- Number of exterior doors obtained from Revit and Allplan models are accurate.

5.2. Limitations of the Study

The limitations of the study are summarized as follows;

- Allplan model is created by the contractor of the project and quantities are provided by them. Therefore, it is assumed that the model is created with correct modeling approaches and provided quantities are extracted from the Allplan model correctly.

- There is not any formwork area tool in Revit. For obtaining formwork areas, add-in named as Sofistik Bimtools in version 2017 which has a function for calculating formwork area is loaded and used for the case study. Therefore, lack of formwork area tool in Revit is one of the limitations of the study, as formwork area calculation features of Revit cannot be evaluated.
- The case study building is modeled in Revit 2017, some of the problems faced with during modeling which are related with software might have been solved in current version of the program. Errors originated from formwork area tool of add-in are checked in 2018 version of Revit and it is seen that same problems exists in 2018 version as well.
- Quantities were compared for each element of the selected construction items. Manual calculations were carried out only when there is a difference in quantities of the elements. Quantities are accepted as correct if there is no difference between quantities extracted from Revit and Allplan models.
- Quantities were compared based on each floor for some construction items such as walls, since there is not any numbering system on the project drawings for these elements. Therefore, differences could not be examined in detail for these construction items.

5.3. Recommendations and Future Work

This research focuses on determining correct modeling approaches in Revit to obtain accurate quantities and comparing quantities obtained from Revit and Allplan models to evaluate the reliability of the results. For this purpose, only some construction items under civil work are selected to be modeled with Autodesk Revit. For instance, steel rebars, interior work items were not modeled in the scope of the study. For the future work, construction items which were not modeled in the scope of this study can be modeled and quantities of these items can be compared as well. Thus, construction items of the building would be compared at a greater rate.

For the calculation of formwork area, other methods can be investigated and applied in order to obtain accurate results. For instance, a new method can be created with the help of Autodesk Dynamo extension, for calculating formwork areas correctly from Revit. Another method such as covering the areas that will be touching formwork with paint objects can be tested to see the formwork QTO calculation results.

Apart from the noted remarks, various design conditions like inclined beams or columns can be modeled and obtained quantities can be checked in order to evaluate the reliability of BIM tools for different design conditions.

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