

TOBB UNIVERSITY OF ECONOMICS AND TECHNOLOGY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**APPLICATION OF PARAMETRIC BUILDING INFORMATION MODELLING
TECHNIQUES ON THE HISTORIC MASONRY STRUCTURES**



MASTER OF ARCHITECTURE

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APRIL 2021

DECLARATION OF THE THESIS

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. This document is prepared in accordance with TOBB ETU Institute of Science thesis writing rules.

Elif Yılmaz

ABSTRACT

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APPLICATION OF PARAMETRIC BUILDING INFORMATION MODELLING TECHNIQUES ON THE HISTORIC MASONRY STRUCTURES

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Documenting the geometric and non-geometric data of historic buildings is imperative to preserve the historical heritage. Acquired data is articulated in 3D by means of various software and digital platform. In this respect, building information modeling platforms are advancing, becoming more accessible and convenient. It is predicted that this system can also benefit historical buildings, and some studies are carried out by a specialist in this regard. This system, which emerged as the concept of HBIM, is useful for conserving or re-functioning historical structures. However, non-standard building elements and complex geometries of historical buildings are the elements that make building modeling difficult. In this study, modeling methods that enable developing the HBIM model of non-uniformly deteriorated historic building elements are investigated. This study aims to examine the potential possibilities of available methods provided in Revit to reconstruct the non-uniformly deteriorated masonry wall of the historical building with smart objects within the scope of HBIM. At this stage, a historical structure with non-uniformly wall is studied as a case study to create an HBIM model. Within the scope of this thesis, the HBIM model of the historical masonry stone walls of the Anavarza/Anazarbus Triumphal Arch, which is a Roman-era structure and located in Adana, is produced with smart objects in Revit Software.

The restitution project of the historical building is used as an underlay within the scope of this project, but this drawing also includes damaged structural elements. This thesis focuses on modeling the non-uniform elements with regular geometries, rather than modeling the geometries of the deteriorated elements of the historical building. In other words, it focuses on digitizing historical building elements with proper geometries. Restitution project modeling is preferred within the scope of this thesis in a short time in order to use time and resources accurately. It is aimed to obtain the necessary data from the Revit software throughout the project duration by processing the geometric and non-geometric data of the historical structure, for which the HBIM model is created. In addition, the positive and negative aspects of the method developed in the model of the Anavarza/Anazarbus Triumphal Arch, which was rebuilt entirely in a virtual environment, are revealed. In this process, it is aimed to create a road map by determining main and intermediate goals.

Keywords: Heritage building information modelling, 3-Dimensional heritage modeling, Standardization methods, Non-uniformly historical building elements, Deteriorated historical masonry wall.

ÖZET

Yüksek Lisans Tezi

TARİHİ YIĞMA YAPILARIN ÜZERİNDE PARAMETRİK YAPI BİLGİ MODELLEMESİ TEKNİKLERİNİN UYGULANMASI

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Tarih: Nisan 2021

Tarihi binaların geometrik ve geometrik olmayan verilerini belgelemek tarihi mirası korumak için bir zorunluluktur. Tarihi yapıdan elde edilen veriler, çeşitli yazılımlar ve dijital platformlar aracılığıyla 3 boyutlu olarak ifade edilir. Bu bağlamda, yapı bilgi modelleme platformları gelişmekte, daha erişilebilir ve kullanılabilir hale gelmektedir. Bu yenilikçi yapı sistemlerinin tarihi yapılara da fayda sağlayabileceği öngörülmekte ve bu konuda alanında uzmanlar tarafından belirli çalışmalar yürütülmektedir. Tarihi yapılarda Heritage BIM (HBIM) kavramı olarak ortaya çıkan bu sistem, tarihi yapıların korunması ya da yeniden işlevlendirilmesi için oldukça önemlidir. Fakat, tarihi yapıların sahip olduğu standart olmayan yapı elemanları ve karmaşık geometriler, yapı modellemesini zorlaştıran unsurlardır. Bu çalışma kapsamında, HBIM modelinin geliştirilmesini sağlayan, standart olmayan ve bozulmuş tarihi yapı elemanlarının modelleme yöntemleri araştırılmıştır. Bu çalışma, HBIM kapsamında tarihi yapının yapı elemanlarının, parametrik modelleme araçlarıyla akıllı nesnelere dönüştürülmesine yönelik bir yöntem araştırmasıdır. Bu araştırma için Revit programında yer alan mevcut yöntemlerin potansiyel olanaklarını incelenmiştir. Bu aşamada HBIM model oluşturabilmek için düzensiz taş dizilimli duvarlara sahip olan tarihi bir yapı örnek çalışma olarak incelenmiştir. Bu tez kapsamında, Roma dönemi

yapısı olan ve Adana’da bulunan Anavarza/Anazarbus Zafer Takı’nın tarihi yığma taş duvarlarının HBIM modeli akıllı nesnelere ile Revit programında oluşturulmuştur. Tarihi yapı, restitüsyon çizimleri üzerinden elde edilen geometrik ve geometrik olmayan bilgileri doğrultusunda modellenmiştir. Zafer takı yapı elemanları restitüsyon çiziminde yer aldığı geometrik şekliyle manuel bir şekilde oluşturulmuştur. Bu çalışmada bozulmuş yapı elemanlarından çok tarihi yapının düzgün geometriye sahip taş elemanlarına odaklanılmıştır. Bu sayede süre ve kaynak olarak kısıtlı olan bir süreçte restitüsyon çizimlerinden HBIM modeli oluşturmanın yöntemlerine odaklanılmıştır. HBIM modeli oluşturulan tarihi yapının geometrik ve geometrik olmayan verilerinin programa işlenmesi ile proje süreci boyunca programdan gerekli veriler elde edilmesi amaçlanmıştır. Bununla birlikte bütünüyle sanal ortamda yeniden inşa edilen Anavarza/Anazarbus Zafer Takı’nın modelinde geliştirilen yöntemin olumlu ve olumsuz yönleri tespit edilmiştir. Bu süreçte ana ve ara hedefler belirlenerek bir yol haritası oluşturulması hedeflenmiştir.

Anahtar Kelimeler: Tarihi yapı bilgi modellemesi, 3 boyutlu tarihi modelleme, Standardizasyon metotları, Düzensiz tarihi yapı elemanları, Bütünlüğü bozulmuş tarihi yığma duvar.

ACKNOWLEDGEMENTS

Foremost, I would like to express my sincere gratitude to my advisor Asst. Prof. Aktan Acar for the continuous support of my master thesis study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor.

Besides my advisor, I would like to thank the rest of my thesis committee: Prof. Dr. Salih Ofluođlu, Prof. Dr. Ali Murat Tanyer, Asst. Prof. Mehmet Koray Pekerıçli, Asst. Prof. Aysu Berk Haznedarođlu, for their encouragement, insightful comments, and hard questions. Also, I want to express my gratitude to the Faculty of Architecture and Design Dean, Prof. Dr. T. Nur ađlar and Head of Architecture Department, Asst. Prof. Murat Sönmez in TOBB Economics and Technology University. Besides, I am grateful to Fatih Gülşen, who is head of the project area excavation, and F. Emrah Köşkerođlu for their support.

My special thanks to Tuna ađlar Karaöz, who supported and encouraged me throughout the process. Moreover, I thank Berkay Barıř alıřkan and Aysema Ülke as my architect companions. My sincere thanks also go to my dearest friends Ceyda Seren Ceyhan and Melis Umay Tekbař for their infinite care and support during our everlasting friendship. Also, I would like to thank my dear childhood friend Vahide Bakır and my lovely cousins Selcen Yılmaz, řule Yılmaz, Ahmet ađrı İnan for their sincere help and encouragements.

Last but not the least, I would like to thank my family: my parents, Nazım Yılmaz, Gülay Yılmaz, and my brother, Alperen Yılmaz. They gave me the determination to pursue my dreams and complete this journey with their limitless love, care and patience. I truly thank my precious family for their faithful support.

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ABBREVIATIONS

BIM	: Building Information Modeling
HBIM	: Heritage Building Information Modeling
CAD	: Computer Aided Design
2D	: Two Dimensional
3D	: Three Dimensional
4D	: Four Dimensional
ATA	: Anavarza/Anazarbus Triumphal Arch
CAM	: Computer aided machining
AEC	: Architecture Engineering Construction
OSS	: Open-Source Software
GIS	: Geographic Information Systems
API	: Application Program Interface
NBS	: National BIM Report
KTB	: Kltr ve Turizm Bakanlıđı
AA	: Anadolu Ajansı
CCW	: Counterclockwise

1. INTRODUCTION

Historical buildings accumulate cultural, social, material, and structural layers during their survival. Documenting and conserving these historical buildings that have witnessed history means conserving history. Various methods are applied to conserve and document historic structures in each period. In addition to the traditional methods used to conserve historical buildings, data-based systems are developed and started to be used in the field of conservation. Building Information Modeling (BIM) system, which has been developing for a while in the building sector, appears as the Historic Building Information Modeling (HBIM) concept in historical buildings. López et al. (2018, p. 1) defined the HBIM system as an emerging technology that provides better understanding and documentation of the historical structure by digitally reconstructing it. This HBIM technology is expressed as a complex system in which building elements' historical and constructional typologies are also included in the modeling. The typology data of historical building elements had to be transferred to a digital model to generate the HBIM model. Accurate data input of the historical buildings and elements that can be structural and architectural information obtained from the historical buildings to the HBIM system is vital for conserving the historical buildings. However, the complex geometries of historical buildings and building elements complicate the process of transferring information to the digital model. For this reason, the Heritage BIM system implemented in non-uniformly deteriorated historical buildings is not the same as the BIM system implemented on the standard new buildings. At this point, different modeling methods need to be investigated and applied for the HBIM system. The purpose of this study is to investigate modeling methods that enable developing the HBIM model of non-uniformly deteriorated building elements. It is expected to develop the HBIM modeling method for non-uniformly deteriorated stone elements. In the most general sense, the main aim of this study is to examine the potential possibilities of available methods provided in Revit for the reconstruction of the non-uniformly deteriorated masonry wall of the historical building with smart objects within the scope of HBIM. In this chapter, firstly, the problems of modeling non-uniformly deteriorated building elements with the HBIM

system have been discussed. In this section, the problems in handling non-uniformly deteriorated historic buildings with HBIM, the literature review of the studies dealing with HBIM systems, and the methods researched and implemented in the scope of this thesis has been explained.

1.1 Definition of the Problem

HBIM is a system that aims to design, model, preserve and manage the information which is obtained from historical buildings by integrating data into the BIM system. Typological, architectural and structural data of historical building elements must be transferred to the digital model comprised with the HBIM system. However, historical building elements have non-uniformly deteriorated over time. The irregular surface geometries of the buildings and various architectural elements whose integrity is impaired are significant factors that make complicating obtain data from the building and make the system nonstandard. Even though almost identical building elements might have been used during construction, forces of nature and human factors impact the building and its components distinctively. Since non-identical architectural elements move away from standardization in the conservation of historical buildings, it can cause problems such as project duration, the accuracy of data, processing of the obtained information into the system and later usage. It is necessary to obtain the current building elements information of the building to digitize these data. This system is traditionally provided by restitution projects. Restitution projects of historical buildings are created manually by obtaining data from the building and converting them into 2D drawings. In this thesis, restitution project modeling was preferred within the scope of this thesis in a short time to use time and resources accurately. Also, this study contains new clues for future studies of HBIM with non-uniformly elements.

1.2 Limitations

Since historical buildings have non-standard and deteriorated building elements, it is challenging to create a 3D model of the historic building by producing smart objects within the scope of the HBIM system. For this reason, methods are determined to analyze historical building elements with irregular geometries and reconstruct them in the digital environment within the scope of this study. The restitution project of the

historical building will be used as an underlay within the scope of this project, but this drawing also includes damaged structural elements. Within the scope of the HBIM model, it is not feasible to model each deteriorated structural element separately. The reason for this is that each element deteriorates geometrically over time. This thesis focuses on modeling the non-uniform elements with regular geometries rather than modeling the geometries of the deteriorated elements of the historic building. In other words, it focuses on digitizing historical building elements with proper geometries. This study is located in a different part from the applied HBIM workflows. However, restitution project modeling was preferred within the scope of this thesis in a short time to use time and resources accurately. Also, this study contains new clues for future studies of HBIM with non-uniformly elements.

There is much knowledge-based software that the HBIM system has accepted. However, the reason for using Autodesk's Revit program in this thesis is that the authors have knowledge of the program's content and operation system. Also, there are too many sources about Revit Software. It is possible to create a 3D model of the deteriorated masonry stone walls of a selected historical building on the Autodesk Revit platform using the tools included in the program. Each historical building element is modeled with smart objects and contains geometric and non-geometric information about the building element. The as-built model created based on the 2D restitution project of the building digitally reflects the current state of the building and its state after the restoration is completed. Since each building element is created in the form of smart objects with the information within the structure of the element, the as-built model carries all the information of the building in total. In this way, the architectural and historical information of the historical building is designed, modeled, conserved, documented and digitized by integrating the HBIM system.

1.3 Structure of the Thesis

This thesis was structured as follows; The introduction section consists of 3 subtitles. In the first part, the problem definition is explained. Following this, in the second chapter, the limitations of the study, the software used in the study and the developed method are clarified. In the third part, the contents of the chapter are briefly mentioned.

The second main title of the study, "Modeling the Geometric and Semantic Information Buildings", consists of 3 sub-titles. In the first title, "From CAD to BIM:

A Brief History", the history of the BIM system until today is briefly explained. Definitions and scopes of the terms that change over time are defined chronologically in the literature. In the second title, "A Specialized Domain: Heritage BIM", the definitions of the term HBIM in the literature, when it emerged, and which programs were used in this process are mentioned. In addition, literature reviews executed within the HBIM scope are examined. Although all of the projects carried out within the HBIM scope have different contents, locations, historical building types, and programs, they are categorized according to the sources of historical building information used.

In the third title, "Operating Manual for Developing Smart Objects for HBIM", information-based modeling steps in Revit program are mentioned. Family types and Adaptive components used to create Complex geometries are explained. With these families in Revit, two different methods are explained in detail to create a 3D model.

In the case study section, the history and architecture of the selected historical building and the implementation processes of the method determined on the building are explained.

In the last part of the thesis, positive and negative aspects encountered during the research process, limitation of the method, future prediction and conclusion are discussed during the research process.

2. MODELING THE GEOMETRIC AND SEMANTIC INFORMATION OF BUILDINGS

There is quite a difference between the building design and construction techniques 20 years ago and today. The architectural practice executed with pen and paper has changed over time. Computer-Aided Design (CAD) systems and then Building Information Modelling (BIM) systems emerged as architectural design mediums in this time period, which started with hand drafting as a way of expressing the architectural idea. However, the BIM system is more than just an expression medium used to produce structures. The BIM system is now a new system change that affects the processes of teaching and practicing architecture. The ways of generating, changing and recording geometric shapes in the CAD system have changed with the BIM systems. This system can be defined as a form of generating 3D geometry and storing information on geometries through external or internal logical factors. Using BIM technology in architectural education and practice is necessary to manage, embrace and express the structure (Russell & Elger, 2008, p. 1).

This section is structured and grouped under four main headings. In the first section, Computer-Aided Design, considered the beginning of the BIM system, will be explained in detail. The historical chronological process of the CAD concept and the role of the CAD concept in its transition to the BIM system in the sector will be clarified. In Section Two, the definitions of the BIM system in the literature and the benefits of the BIM system throughout the construction process will be shared. In section three, the acceptability and availability of the BIM system worldwide and the application of the BIM system in historical buildings will be discussed. The definitions of this system, encountered as the concept of Heritage BIM, in the literature, its differences from the BIM system, its limitations and benefits will be explained. In the last section, general modeling mediums of Autodesk's Revit program, which is one of the platforms that will form the basis for creating BIM and HBIM systems, will be examined. The different methodology will be applied to create the HBIM model of the

deteriorated masonry wall stones as smart objects with the modeling tools included in Autodesk's Revit program. In the sub-headings of this section, first of all, the modeling tools on the Autodesk Revit platform will be explained with the aid of visuals. Then, using the modeling tools included in the program, a modeling experiment of a masonry stone wall without a standard sequence will be carried out. These experimental works will be conveyed supported by visuals.

2.1 From CAD to BIM: A Brief History

Computer-aided design is a system that focused on solving complex design problems in architecture in the 20th century and became more practical over time. In the 1900s, architectural building drawings taking much time and requiring much workforce play a significant role in the spread and adoption of CAD systems (Lei& Weifang, 2012, p.798). The computer-aided design allows to carry out the project processes of different disciplines with the help of computers. It provides a digital ecosystem where design, data generation and accumulation, collaboration and management are processed interactively.

Designing and arranging building element shapes and features in a computer environment in 3D provides a broader perspective. Besides 3D representation tools such as plan, section, view, detail, it is also easy to obtain. Orthographic views, details and 3D perspectives are developed through digital tools. Computer-Aided Design (CAD) provides convenience to the designer in the design and implementation process owing to these 2D and 3D features. The CAD system is an essential collaboration and interaction between computational power and humans in solving complex designs, producing concept design simulations, and facilitating interdisciplinary coordination and decision-making. Pérez-Sánchez et al. (2017, p. 45) divided the stage of the construction industry into three phases: The Manuel phase, the digital phase, the BIM phase. The change between these phases took a long time, and each phase developed to adapt to each other.

The presentation and drawing processes of the project are quite fast and accurate with the speed, intervention ability and different viewing options provided by the computer. Computer-aided design is briefly CAD, designing with the aid of a computer (Autodesk, n.d.). It can be said that computer-based systems are used to produce

projects easier, faster and cheaper from many different disciplines in professional life and education life (Savage, 1985, p.38).

The history of the BIM system begins with the CAD system that emerged by large industries in the 1950s and 1960s. CAD systems had the benefit of large industries in saving time compared to 2D manual drawings. Over time, the recognition and commercial use of CAD systems is increased. The CAD system enables the products to be produced directly on the computer without the need for preproduction. At that time, while only 2D drawings were generated in CAD systems, the process of modeling 3D objects started over time. Computers needed software that would perceive the surfaces of the object, generate and perform mathematical calculations for 3D modeling. While CAD became more accessible and available in the 1960s and 1970s, the usage cost of this system was considerably excessive. At the end of the 1970s, systems' costs became more affordable with the developments in software and hardware. In the 1980s, the CAD system is used in personal computers. In the early 1990s, softwares were developed to simulate a building's response under different conditions and simultaneously, parametric softwares were developed in the construction industry at that time. All of these developments in the early 2000s led to the formation of BIM systems. Over time it evolved into a system that is the 3D model is inadequate, the 4th dimension is added to the design, and cost-energy calculations can be achieved. The awareness and usability of BIM systems in the construction industry will increase over time, like the CAD system. (Barnes& Davies, 2014, pp. 5-8).

Mitchell first examined the concept of CAD in his book Computer-Aided Architectural Design (Schmitt& Oechslin, 1991, p.13). The principles of computer-aided design in the design process, computer features, the role of the computer in design have been investigated (Mitchell, 1977).

CAD systems have been a major breakthrough in the construction industry with provided in the project process in the 20th century. However, new systems that support different ways of thinking have emerged in architectural practice, and the CAD system has become old, traditional and inadequate systems with the developing technologies in the 21st century. New systems have been created that differ from conventional methods in the construction industry with the development of technology. Architecture - Engineering - Construction (AEC) technology has improved from both CAD and

BIM perspectives with software developed companies such as Autodesk, Bentley, Nemetschek. Thanks to software such as Autodesk's Autocad, Architectural Desktop, Auto Architect, Revit, Navisworks; Nemetschek's Allplan, MiniCAD, ArchiCAD; Bentley System's Bentley Architecture, Microstation, TeamMate new systems have been developed in the AEC industry (Wierzbicki et al., 2011, p. 142). Along with these new systems, new forms of architectural expression and programs in which these forms of expression can be created have emerged. The conventional production manner of different disciplines and project stakeholders in the building industry has changed considerably with the developed new systems. BIM is a multidisciplinary system that has existed in the new building industry sector for a while, and a new era has started in the AEC sector with what BIM provides.

BIM system can be defined as a digitally monitored process where all building assets come together to comprise the whole building (Antonopoulou & Bryan, 2017, p. 1). Eastman et al. (2011, p. 1) state that the building digitally modeled with the BIM system during the design process provides more accurate analysis and control when compared to manual modeling. This system accurately contains all the data required to promote the construction, fabrication, and procurement activities of the relevant building, which is digitally built-in 3D in the computer environment. Also, the Autodesk community, one of the platforms containing the BIM system, briefly defined the BIM system as an intelligent 3D model-based process (Autodesk, n.d.). In the BIM process, building elements are represented by 3D intelligent objects that carry geometric or non-geometric data about themselves (Eastman et al., 2011, p. vii). In other words, intelligent objects can be defined as the representation of the actual building element in the virtual environment with its data content.

Building information modeling is the process of designing, generating, managing data through the life cycle of the building. During this process, particular softwares are used as a medium of expression in the BIM system. The various elements of architectural, structural, mechanic, infrastructure and electrical disciplines are parametrically modeled with these programs, and their relations with each other are designed.

Technically, it is possible to claim that BIM is a parametric modeling system where each building element is represented by intelligent objects. These objects contain 2D-3D geometric as well as non-geometric data. Parametric BIM objects consist of variables information regarding the building to which it belongs determined by the

designer. Throughout the project process, the model becomes digital information resources through these parametric objects (Antonopoulou & Bryan, 2017, p. 1). The project is comprised of intelligent objects in the BIM system that contain data about the building and the relationship of these objects with other parametric elements. In this sense, it can be said that technology does not only affect drawing and visualization in the construction industry, but it also affects and changes the design process of project stakeholders. Khemlani (2011, p. viii) emphasized that the BIM system is not a technological change. It is a system change that includes all the elements that form a building. In the BIM process, despite the problems that can be overlooked in conventional 2D methods, solutions are generated in the project process without going through the construction process. One of the main reasons for this is that the building is constructed in 3D in a virtual environment. Barnes & Davies (2014, p. 5) determined BIM term as a process of a 3D building in the virtual environment where the effects of changes in the project during the design process to the project will be actually the same as the real building's response.

The BIM term has been described with various technical or general definitions so far. Different users in the construction industry or academy addressed this term from different perspectives. Murphy et al. (2011, p. 2) defined the BIM term as the combination of parametric elements in the 3D virtual environment. These parametric objects form the whole structure by coming together and interacting with other objects in the building. Therefore, parametric objects are not singular, and they can be defined as part of a whole. Parametric objects determined by the user are attributed some geometric or non-geometric data along with the project. These data create a comprehensive information repository for the user at the end of the project. There are specified rules established by the user in this system called object-based parametric modeling. Eastman et al. (2011, p. 31) state that these parameters and rules are an expression that can be related to other objects of the building. Therefore, this allows objects to be automatically updated according to user control or changing contexts.

The BIM term can be understood as the continuation of CAD drawing programs that emerged as a result of substantial technological developments. However, BIM stands in a quite different position from CAD programs. It would not be correct to define this system as just a modeling program. BIM is a platform where all project users must be involved in the project process. Otherwise, it does not differ from other types of 3-D

modeling programs. Kensek & Noble (2014, p. xxiv) express that BIM has natural progress in computer technological evolution in some ways but emphasized that BIM is not CAD in this process. Also, BIM has revolutionized the area of execution, documentation and changed the nature of the project of conventional sense of design, execution process. McArthur (2015, p. 1106) also stated that BIM is not just a simple 3-D CAD tool, and with this system, design-production, multidisciplinary coordination, cost estimating, construction scheduling, analyses, 3D design can be achievable.

According to Russel & Elger (2008, p. 2), the Architects have drawn in the past, they are still drawing today, and it is obvious that they will draw in the future. Architectural building elements are not expressed with lines; Instead, each building element is expressed with 3D models. For these reasons, world-renowned offices are trying to change their design methodologies. Russel & Elger (2008, p.2) interpret that BIM is a methodology change and integration of semantic layer into the 3D parameter object. Thus, at the end of the project, a building or data model is created that all project stakeholders can access, use and manage. Russel & Elger (2008, p. 3) defines the non-geometric data form as semantic data in their article. While a line drawn in the CAD system expresses a wall element, a line drawn in the BIM system has thermal, acoustic, structural and physical data of the wall. The non-geometric data of the building element is called "semantic data." An example of this is the brand of the element.

The management and planning processes are as important as the design and production process in the construction industry. In conventional project methods, there are specific issues such as manual calculations, different platforms and programs such as Microsoft Excel, Word owned by different disciplines such as civil engineers working on quantity takeoff, the transmission of total data revealed at the end of the project. Data losses and miscalculations in interdisciplinary data transfer are prevented due to a single platform and information repository in the BIM system. Compared to conventional methods, BIM has much faster, cheaper and more accurate data in creating cost estimation, material quantity takeoff (Ren, Skibniewski & Jiang, 2012, p. 642). Although only the geometries of the building elements encountered in the current conservation studies of historical heritage buildings are addressed, the BIM system also includes semantic data about the building outside of the geometric information. In addition, BIM is used as a platform that combines material and

construction process information (Fai, Graham, Duckworth, Wood & Attar, 2011, p. 16).

2.2 A Specialized Domain: Heritage BIM

The BIM platform brought a new point of view to the new building design, process and planning in the construction industry. Also, the AEC sector, which includes different disciplines, has come to a different position with this system. However, the operation of the BIM system in the new building construction process is not the same in historical heritage buildings. Historical buildings differ from the new building design with their building geometries and historical asset underlying their geometries. Historical buildings and monuments are the embodied knowledge of their own time of construction and survival. That knowledge is of importance for today and the future in many respects. The heritage buildings have been tried to put under protection by specific conventional conservation methods until today. In recent years, different studies are carried out to preserve the historical heritage with the aid of developing technology. Each of these studies was created from different perspectives using the HBIM system. Baik et al. (2013) has created a particular library for Historical Jeddah and the Nasif Historical House in Saudi Arabia. Oreni et al. (2013) created 3D model surfaces for wooden vaults and bean floors and the Basilica di Santa Maria di Collemaggio in Italy using point cloud and photogrammetry. Dore et al. (2015) created Structural simulations and conservation analysis for The Four Courts in Ireland. After the BIM system was involved in the new building design and construction process, studies on the utility of historical heritage preservation projects were also conducted. BIM platform and historical building integration is a new method for managing and documenting the listed building. This method has been merged under the name of HBIM (Baik et al., 2013, p. 73).

Murphy et al. (2009, p. 311) used the term HBIM for the first time in his study at the Dublin Institute in 2009. He defined the HBIM term as an innovative solution consisting of historical data and each architectural element with historical details that it carries beyond its visible geometric surface. There are various uses of the HBIM term in the literature and construction sector, such as Heritage BIM, Historic BIM, Heritage building information modeling. In the HBIM system, how the BIM system's process methodology can be used in historic buildings is a new subject in the

conservation, documentation, and re-functioning of existing historical buildings' studies. So, this new process is still being investigating and researching by regarded as specialists on the subject today. Historical building modeling and documentation can be stored in a holistic manner. HBIM is a system that allows the understanding and advertization of the historical building by reconstructing the buildings as 3D in the computer environment with cutting-edge technology (López et al., 2018, p. 2). Oreni (2013, p. 349) states that the BIM system can be used in historical documentation and conservation management today, although it is used in the first new building construction. However, methodology and new project studies are required for 3D models of irregular geometric shapes of historical building elements. Therefore, a beneficial study is acquired for the conservation and management of the historic building.

HBIM is the process of modeling and managing the artistic, historical, and constructive typologies of historical building elements (López et al., 2018, p. 14). The production, transfer, exchange, and interpretation of the common project data that exist in the BIM process between different disciplines in the AEC sector is also included in the HBIM process. Historical building projects depend on multidisciplinary collaboration. Complex information of the building put across the historical building's value and historical accumulation (Antonopoulou& Bryan, 2017, p. 3).

There are various geometries of historical building elements. These geometries vary throughout history at different periods and geographies. For this reason, it is not possible to standardize and model various historical building elements belonging to different historical periods with the BIM system as in the new building model. Various mediums are required for 3D modeling of the complex geometries of the building elements with the HBIM system in the computer environment. Modeling these complex and irregular surfaces of historical building elements provided in the Revit platform in "adaptive component", "adaptive family", "mass model" and "model in-place" categories is possible. These tools will be explained in detail in the case study section of the thesis. Although new methodologies and modeling tools are experienced, the process of reconstructing historical building elements with complex, unequal and irregular surfaces in the computer environment is ambiguous within the scope of the HBIM system. The functioning methodology has not been established yet as much as the BIM system, which has been adopted in new building design and

construction process. The as-built BIM model can be used in historic and new buildings, but the BIM methodology of historical buildings differs from the new buildings. Although it is becoming widespread to build new buildings with the BIM system globally, the buildings constructed now on earth do not have a computer-registered model. In Europe, 80% of the buildings were built before 1990, and most of them do not have an as-built BIM model in which the HBIM process can be managed (Rocha et al., 2020, p. 47). For this reason, there is an irreversible loss in an adverse situation that the buildings will encounter in the future. Due to the adverse condition encountered over time, non-standardization of the historic buildings and building elements that have been damaged and whose integrity is impaired makes it challenging to model in 3D. Complex and irregular geometries and non-standard building elements of historical buildings lead to a lack of data and waste of time in conventional conservation methods (Rocha et al., 2020, p. 47). According to Maxwell (2014, p. 10), it is difficult to say that we have come a long way in HBIM progress, and an entirely accurate methodology has not been established to reveal the 3D model of historical buildings with different architectural periods, styles and structural compositions with the HBIM system. Today, different methodologies have been developed for the HBIM process by experts from both academic and construction sectors. It is not possible to say that a precise, accurate, easy and quick system methodology has been developed in the historical buildings within the scope of the HBIM system. While academic and sectoral studies continue under the name of HBIM to preserve and improve the historical heritage in the world, there are some case studies to produce and manage data in historical buildings.

In order to conserve, document and record the historical heritage, the HBIM process is carried out with definite benefits provided by the latest technology. Unlike the BIM process, the HBIM process has a building with historical and architectural values built in the past, and analyzing the historic building is the major part of the process. Each building element has particular importance for the whole building, and in the process, the analysis should be done and documented. Obtaining the architectural, structural, mechanical, electrical, infrastructure disciplines' project information from the existing historical buildings is the first stage of the HBIM process. At this point, with the development of technology, visual data about the historical building are obtained with remote sensing tools developed over time (See Fig.2.1). HBIM is a 3D parametric

representation format in which 3D historical building elements and data are modeled and managed. The data received over the historical building is integrated with the 3D model. Thus, an as-built model is generated with the highest technological survey techniques such as laser scanner point clouds, digital orthophoto, digital photogrammetry, monitoring data (Oreni, 2013, p. 349).



Figure 2. 1 :Laser scanning process to create a point cloud and Georeferenced point cloud, (X, Y, Z). Source: López et al. (2018, p. 8).

In this process, geometric, typological, semantic data obtained from the building is necessary to model the parametric model or parametric objects. The process of creating an as-built model by modeling each element of the historical building with this obtained information is called reverse engineering (López et al., 2018, p. 8).

The historical building conservation and research process is a multidisciplinary system. In this process, professionals from the domains of architecture, structure, mechanical, electrical, infrastructure disciplines provide information about the historical building of their field. Both the information produced by the specialist from other disciplines and the designer produces new information related to their own fields. The accuracy and completeness of the information produced for the historical building affect the investigation, intervention, conservation, maintenance process. The decision and the information added about the situation of the elements that concern the different disciplines of the building in the process are of great importance for the whole of the historical building, and any mistake can lead to irreversible consequences. For this reason, multidisciplinary data management and data transfer are of great importance in every phase of conservation methodology (Simeone, Cursi, Toldo & Carrara, 2014, p. 682).

Academic publications in the field of HBIM have specific topics and scopes. All these publications carried out to conserve historical buildings and building elements illuminate a different point of the conservation process. Since a definitive solution has not yet been created in the HBIM system, investigations and researches on this subject are quite substantial.

López et al. (2018) studied a comprehensive compilation of all the projects with the BIM-HBIM process methodology are examined between 2007-2018. It is possible to state that most of the studies among the analyzed publications focus on data acquisition technology. Also, in only a few of the studies focus on automation of the reverse engineering process, interoperability, management, documentation, and maintenance of the as-built model. Analyzed publications, which are collected in 4 categories, are divided according to the types of tools used in the projects. Accordingly, there are studies using Autodesk's Revit software and Graphisoft's Archicad software in HBIM publications. Also, studies are using BIM platforms and auxiliary tools Programs such as Open-Source Software (OSS) which are DAYSIM, EnergyPlus™, 3DReshaper, BIM3DGS, (Application program interface) API, which are GreenSpider plug-in, NURBS plug-in, 3D "RULED" plug-in and Rhinoceros. In addition, studies are using different programs such as Open-Source Software (OSS), non-BIM auxiliary tools, which are AutoCAD, SketchUP, 3DStudio Max with geographic information systems (GIS), City GML, Sketchup, TEMCAR, SIGEC with BIM platforms. Lastly, studies are using some special programs developed by researchers for the HBIM system and other programs like Rhinoceros, Autocad, OSS, API are used to model historical building. As a result of the analysis, it shows the number of studies using the software specified on the graph in the HBIM system (See Fig.2.2).

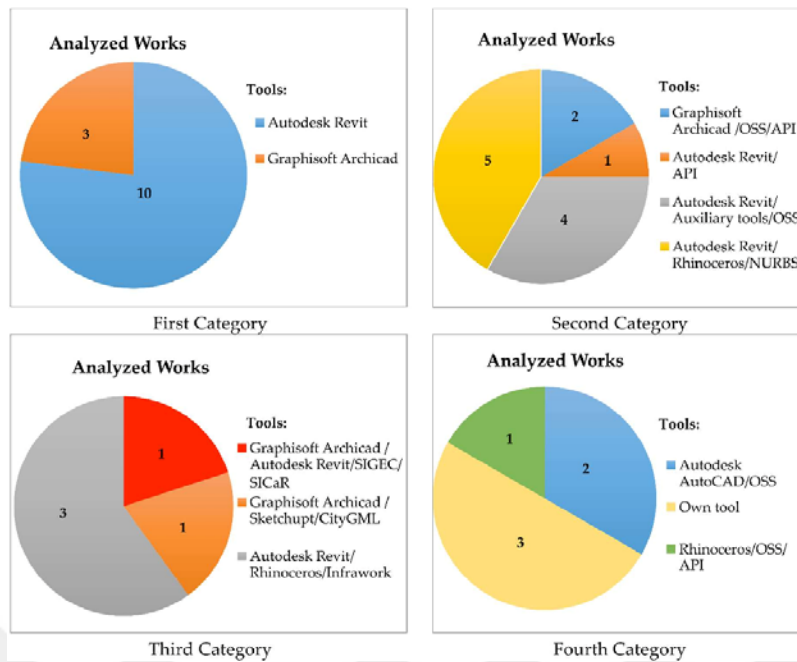


Figure 2. 2: Program analysis used in the HBIM system. Source: López et al. (2018, p. 16).

The HBIM term is discussed in different studies and defined with different approaches within the scope of each project. The HBIM process generation model of historical structures was revealed as a result of the various workflow of the publications. Although the studies carried out in the HBIM process have a common goal, the methodology of reaching the target of each study has differed. There are decisive reasons for the differentiation of workflows in HBIM studies. It can be stated that the factors that create this differentiation are the technologies used in the project, the variety of facilities, the project budget, the deterioration level of the historic structure and the profession of the specialist who executed the process. It is possible to claim that there are different workflow approaches in HBIM studies based on research on HBIM publications.

According to the analyzed HBIM publications, it can be stated that there are four different HBIM approaches. The first of the HBIM approaches is analyzing the historical structure and digitizing the structure with the obtained data using BIM tools. In this approach, firstly, a collision is detected using a laser scanner, photogrammetry technologies and the archival documents of the historical structure. In this way, it is aimed to create the most realistic digital model of the historical building. In other words, different sources are used for the digitalization of the historical structure in

studies with this HBIM approach. In this way, the collected data is converted into digital models with BIM tools.

Del Giudice & Osello (2013) managed the HBIM process with on both geometric survey and archival documents to control the accuracy of data. They developed a process to generate a 3D model of historic structures. Different guideline experiments were made to increase interoperability in the BIM system with cut sections, levels, grid elements. The case study analyzed consists of the refurbishment of the former thermal power plant of Politecnico di Torino. Geometric survey and research based on the archival documents are carried out due to the importance of the context analysis. The geometric survey process was managed with both a total station and a laser scanner to control data accuracy from different sources (See Fig.2.3). This process that takes place in different disciplines was handled through Revit software, one of the BIM platforms. The first step in this study is to determine the consistency between the laser scanner and the archival document. For this, structural grids were overlapped with the point cloud document, so the various data types acquired from different sources were combined in a BIM environment (See Fig.2.4). All building elements are assigned to the temporal phase related to the time, so all elements were modeled 4D. Although it is an advantage to integrate data obtained from different sources on a single program, it also has some disadvantages, such as the need for computer hardware that includes large quantities of data.

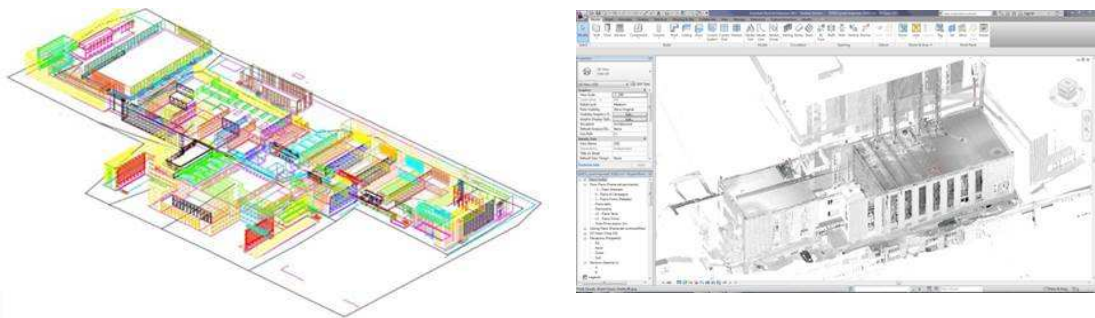


Figure 2. 3: Survey of the Main Campus realized using a total station and Point Clouds of the old thermal power. Source: Del Giudice&Osello (2013, p. 227).

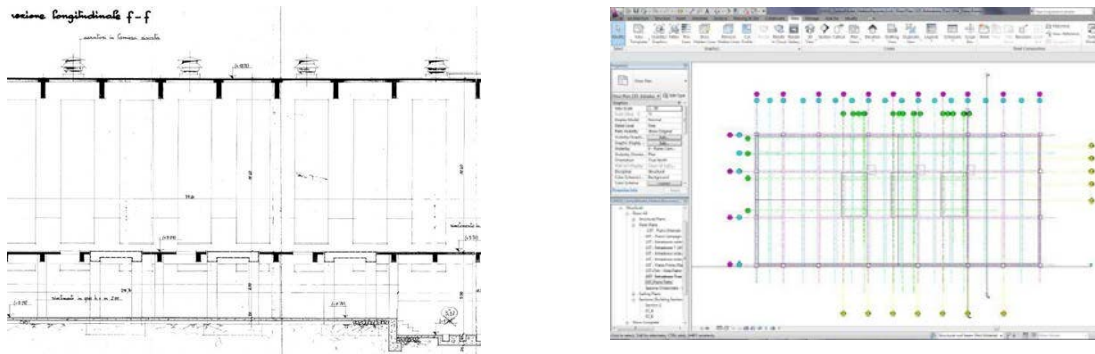


Figure 2. 4: Longitudinal section of the old thermal power, coming from archival documents and Image of the structural grids. Source: Del Giudice&Osello (2013, pp. 227-228).

Brumana et al., 2013 is also used a similar workflow to link point clouds with the BIM Autodesk Revit platform. The study aims to bring together content information on buildings, which are material, decay, stratigraphy, and survey technologies on the historic structure. The process was carried out by linking the point clouds model obtained from the "St. Maria in Scaria d'Intelvi" historical building, selected as a case study, into the BIM environment. As a result of the analysis performed on the structure, the processes of historical building elements that have changed and differed in time are determined, and each period is expressed in different colors in the BIM model (See Fig.2.5). Thus, an as-built BIM model is created that includes visual data of the change of historical building over the centuries. The BIM model serves as a common knowledge tool through historical phasing (See Fig.2.6).

In addition, another purpose of this study is to make energy analysis possible after the BIM model of the historical building is created. 3D BIM model is used for energy analysis with the appropriate tools for the life-cycle building management and energy efficiency at the end of the process. Green Building Studio plug-in was used in this process. However, according to the authors, to support future studies, different levels of simplification and behavior of non-strict historical building elements with deteriorated geometry should be better analyzed.



Figure 2. 5: HBIM of the different constructive phases of the building.
Source: Brumana et al. (2013, p.500).

cent. XV	?? first fresco cycle. Bell tower?	1753	completed church's floor, realized vault's frescos in first and second spans
cent. XVI	?? second fresco cycle	1754	completata baptistery's floor, end works in Crocefisso's chapel
1593	pastoral visit of Como's Bishop	1757	chancel's step and balauster
1599	first statement about baptistery's recess	1764	?? end "Virgin's coronation" fresco (second span)
cent. XVII	?? cloister in the facade? Main altar	1772	roof completed, marble steps placed at the altars, main altar and bapistery adjusted
1635	statement about the presence of Genovesi's chapel	1775-1800	end of works: roof, facade, sacresty, wooden door finishes, pulpit adjusted
1708	start works in the choir	cent. XIX	Genovesi's chapel and baptistery's gates
1710-11	end building new walls + choir's roof	1963	demolition old parish house + built new one
1718-20	start works in the sacristy	after 1975	latest restoration interventions
1721	start nave's walls works		
1724-26	chancel's decorations		
1741-46	facade decoration, statues' positioning		
1740-50	chapels' transformations		
1752	still not realized paintings in the chapels, chancel's walls frescos, decorations in first and second spans		

Figure 2. 6: Historical transformation of the church: the different colors represent the different historical construction phases. Source: Brumana et al. (2013, p.500).

The second HBIM approach is analyzing the historical structure with laser scanner technology, digitizing the data using BIM tools and creating an HBIM library. In this approach, historical details of analyzed historical structural elements are documented in the HBIM library. In this way, the elements are both documented with their

geometric and non-geometric information reflecting the period they belong to and can be reused for other studies.

According to Murphy (2011, p. 6), the HBIM process consists of three stages. The first step is obtaining and processing survey data from the historical building (See Fig.2.7a). Data acquisition is carried out with remote sensing tools (See Fig.2.7b). Stage two is the determination of the historical details of the period that the building was in by using the architectural pattern book and the construction of the details on the objects. The third and final stage of the HBIM process is the correlation of the information obtained and produced in the first two stages (See Fig.2.7c). After these stages, the model of the historical building is formed (See Fig.2.7d). The architectural pattern book is a manuscript in which detailed hand drawings are made to introduce and document architectural building elements dating back to the 18th century. Parametric objects modeled according to the pattern book are mapped onto the survey scan data at the last stage. In this way, the entire historical building is created from engineering survey drawings. The as-built 3D BIM model consists of actual materials and suitable construct methods for the nature of the materials with the aid of the architectural pattern book. In HBIM, historical building elements are modeled as smart objects and coincided with point cloud data or image-based surveys. In this process, a 3D as-built model is obtained with not only the geometries but also the historical value of the building elements. Architectural representation expressions such as 2D section, elevation, plan, detail or documents and schedules belonging to different disciplines can be obtained from the 3D model provided by the HBIM system. Architectural, structural, mechanical information assigned to the building elements come together in the process or at the end of the project, providing project-based or element-based control and editable documentation to the designer or user in HBIM processes carried out with smart objects.



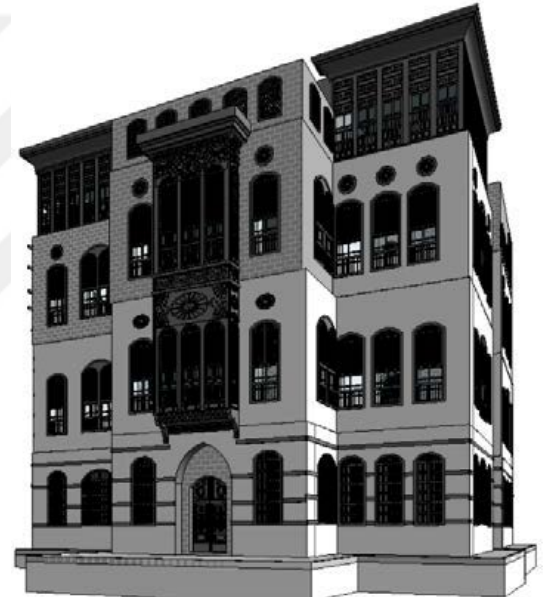
(a)



(b)



(c)



(d)

Figure 2. 7: (a) Historical building/Nasif historical house, (b) 3D point cloud of historical building, (c) 3D section on the HBIM model and the point cloud, (d) 3D As-built model. Source: Baik et al. (2015, pp. 29-31).

López et al., 2017 also developed a methodology consisting of three stages on a case study. It is aimed to convert laser scanning or photogrammetric data from historical structure to HBIM elements and create an HBIM library with these elements within the scope of this study. Building elements were modeled with fast and semi-automatic modeling on a monument of the Spanish Romanesque period case study.

This study consists of three main steps. The first step of the process is the collection of historical data; It is divided into two sections as graphic/space data collection and non-graphic (semantic) data collection. The space data collection section covers

internal and external surfaces information acquired via laser scanner technology and finding information about dimensions of the building. The semantic data collection section covers finding information about the building, which are historical archives, drawing of the historical pattern, type of materials, construction methods, social, cultural situations. Etc.

The second step is the data analysis and organization of the historic structure to be transferred to the BIM system. In a more technical sense, this step can be explained as the filtration process, cleaning and softening of the point cloud. Raw point cloud data type becomes utilizable after specific processes such as cleaning and filtering.

The third step of the process is importing and storing the point cloud data into the BIM system. The building elements analyzed in the case study are divided into two categories as regular and irregular surfaces. While building elements such as capitals, archivolt, and ornaments, are irregular; Building elements such as columns, walls, windows are included in the regular category.

3D parametric modeling of the structure is carried out with added 3D sections, views, levels and grids from different sections on the point cloud. Simple geometric elements of the structure are modeled in the BIM environment with existing libraries, while building elements with complex geometry are modeled construction of external parametric objects to the project. The historical building elements were combined within the scope of the HBIM library and served as the open-source library (See Fig.2.8).

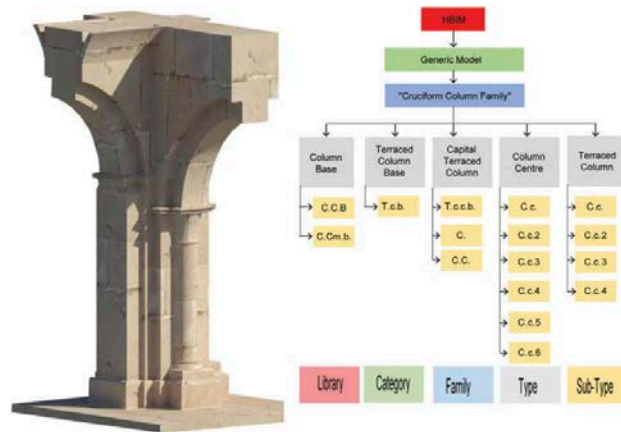


Figure 2. 8: Cruciform column, Types and sub-types that make up the modeled families and Longitudinal section, where the cruciform pillars with semi-columns and barrel vaults separated by arches that cover the central nave. Source: López et al. (2017, p. 983).

Baik et al., 2013 aimed to create JHBIM (Jeddah Historical Building Information Modeling) model, which covers all engineering drawings with the laser scanning survey data (See Fig.2.9a). Also, this developed approach provides a detailed 3D model which contains the combination of building information modeling and Geographic Information System (GIS) via Autodesk InfraWorks platform.

JHBIM process consists of a Hijazi Architectural Objects Library. This Library was comprised of Islamic historical manuscripts and pattern books. This process consists of 3 main stages. The first one is generating the model based on laser scanning survey data and image survey data (See Fig.2.9b). The second one is importing the JHBIM model into Autodesk InfraWorks, and lastly, importing the GIS data provides semantically rich models, documentation and analyses of heritage sites (See Fig.2.10).



Figure 2. 9: (a) 3D Point cloud model, (b) 3D model by Autodesk Revit.
Source: Baik et al. (2013, p. 75).

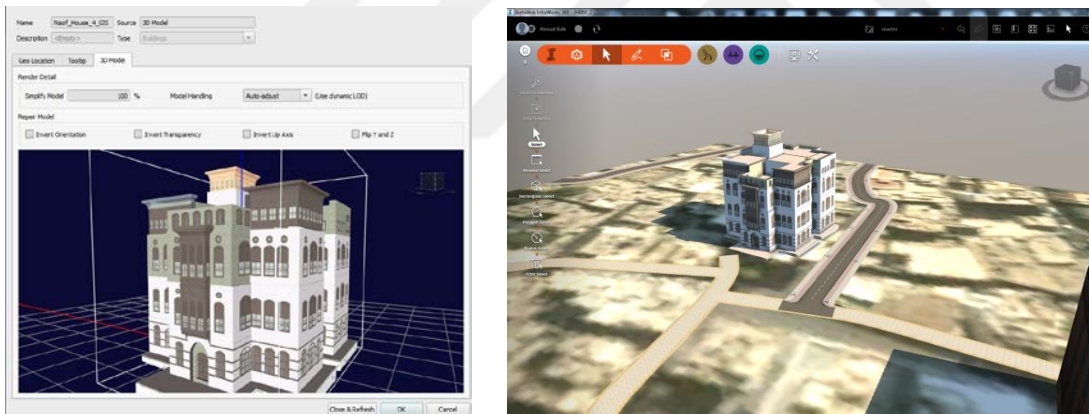


Figure 2. 10: The 3D JHBIM model in Autodesk InfraWorks and Integrating vector and raster data with the JHBIM within Autodesk InfraWorks. Source: Baik et al. (2015, p. 32).

The third HBIM approach is analyzing the historical structure with laser scanner technology and digitizing the data within the framework of developed algorithms and rules. In this approach, after analyzing the historical structure, the deteriorated historical elements are separated and digitized through algorithms.

Dore et al., 2015 created the HBIM model of the Four Courts historical structure in Dublin with historical documents, physical-constructive analysis, and point clouds data. In 2014, a laser scanner survey was conducted of the internal and external facade

of the historic structure. The processing laser scanning data HBIM model is created of the damaged part of the building. The HBIM system is discussed in two different workflows within the scope of this document. The first methodology of this study is the model generated from the historical data; the second methodology is a procedural and segmented model acquired from the survey analyzes, laser scan of the damaged part of the structure. Structural decay simulation was created with two methodologies for documentation analysis. Two different data sources were used for historical structure analysis. The first is an archive of historic surveys, which are drawings, documents and iconographic sources of the specific building; the second is laser scan survey data set acquired from the structure.

The HBIM model of the historical building was created with two different sources. In this process, the damaged part of the historical structure was modeled as a procedural and segmented model from the laser scan. Firstly, procedural modeling is carried out with rules and algorithms developed to combine parametric library objects and survey data. Secondly, segmented point clouds and cut sections are imported into the BIM environment (See Fig.2.11). Lastly, procedural rules were carried out on survey data to generate geometries (See Fig.2.12). Then, these geometries are fixed with parameters for accurate coincidence. The procedural rule is a plug-in developed for modeling facades of historical structures geometries. This rule allows for semi-automatic modeling from survey data. Deteriorated historical building elements are modeled accurately with procedural rules plug-in.

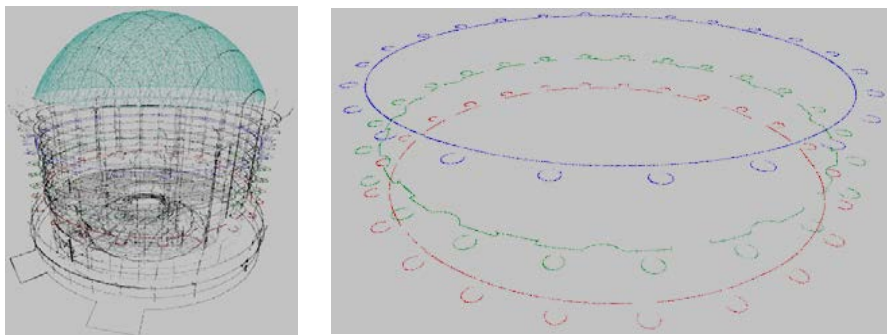


Figure 2. 11: Segmented point cloud and horizontal cut sections imported into BIM software. Source: Baik et al. (2015, p. 354).

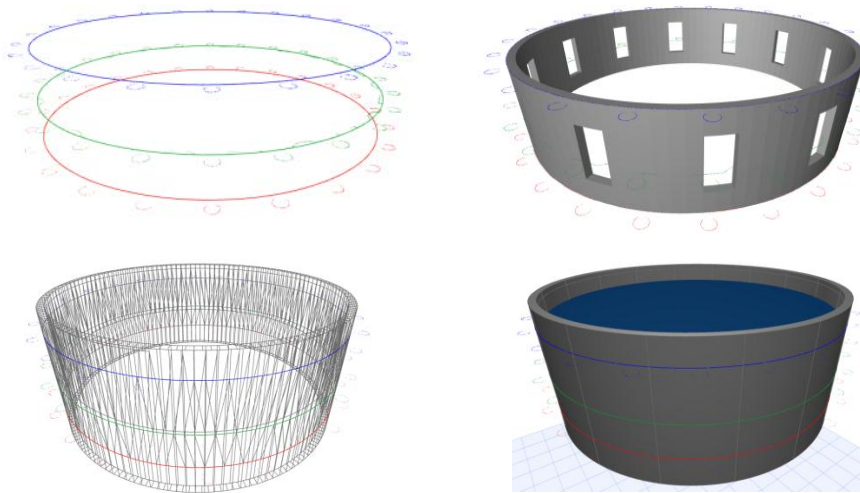


Figure 2. 12: Irregular non-vertical walls containing deformation automatically generated from cut-sections. A split rule is used to automatically add window openings. Source: Baik et al. (2015, p. 354).

The fourth HBIM approach is analyzing the historic structure with the photogrammetry method and digitizing the data with the new software prototype developed. In this approach, after analyzing the historic structure, the deteriorated historical elements are digitized with the developed software prototype.

San Jose et al., 2013 developed a new open-source software prototype for interactive volumetric visualization of complex architectural objects. This software is based on international standards for e-learning of conservation and rehabilitation tasks in Architectural Cultural Heritage. Also, this application was designed to support different functionalities such as scalable, compatible with different formats, connecting with standard tools for urban GIS and provides support for identifying and tracking interventions. Finally, all result obtained from the study is illustrated on very damaged churches and an urban district of Segovia (See Fig. 2.13).



Figure 2. 13: Reconstruction and intervention phase of a damage cultural heritage building. Source: San Jose et al. (2013, p. 371).

There are different approaches in the literature of digitally modeling and documenting historical buildings within the scope of the HBIM system. Each study in the literature about the HBIM system has a scope that contributes to the understanding, development, modeling and documentation of the historic structure.

It is possible to claim that there are different workflow approaches in HBIM studies based on research on HBIM publications. Although there are different approaches in HBIM publications, the common point in all of these studies is to digitize historical structure geometric and non-geometric data accurately. The tools, technologies used in the studies and the preferred methodology within the program to generate an HBIM model varied according to the requirements of each project. The substantial point is to develop different methods for digitizing historical building data in each study. At this point, between the HBIM workflow stages, this thesis focuses on the HBIM modeling based on the restitution drawings created from the historic building. As in every study, the aim of this study is to digitize and document historical building data. However, in this project, instead of obtaining data from the historical building with remote sensing tools, it is aimed to benefit from the restitution drawings containing geometric and non-geometric data obtained from the historic building.

2.3 Operating Manual for Developing Smart Objects for HBIM

Revit is software that supports the BIM system developed by Autodesk Company. Revit is one of the most common software used to start the concept project and finish the project with construction and documentation. According to the results of research

conducted with 1000 architecture firms in the BIM report undertaken by The National BIM Report (NBS) published in 2020, 50% of companies prefer Autodesk Revit in their projects (See Fig.2.14). Also, this rate had increased steadily since 2011, when the research was first conducted (The NBS, 2020, p. 25). There are specific reasons why Revit is the most widely used among the programs that adopt the BIM system in the world. It can be said that the most important of these reasons is accessibility. The widespread usage of this software in most countries around the world increases its accessibility and usability. Fixing errors and updating software regularly are also significant factors. The use of Revit makes it easier to find a solution to a problem encountered within the program. There are many internet resources, social media platforms and forums for Revit software, and solutions can be brought to the problem with the aid of these sources. Another advantage of the Revit program is that it can be associated with other products of Autodesk. Common files, platforms are required for the architectural project to be integrated with other disciplines, and this integration can be achieved with different software provided by Autodesk.

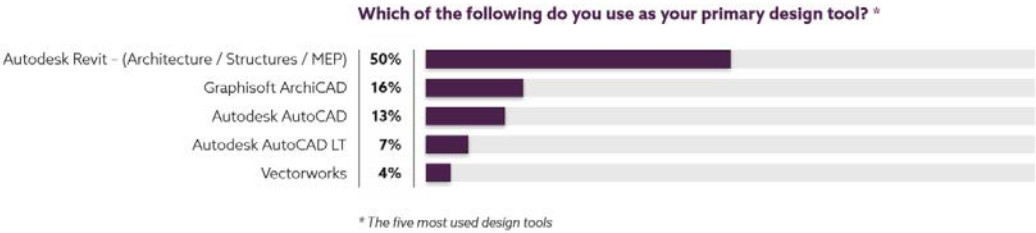


Figure 2. 14: Program analysis used by architecture offices. Source: National BIM report (2020, p. 25).

Revit software provides 3D and 2D forms to improve the design. 2-Dimensional plan, section, elevation, perspective view, the orthographic view can be obtained from the 3D model created in Revit. Also, building performance analysis, solar analysis, material quantity takeoff, project schedule information can be obtained in all project steps. The designer can improve the design by navigating around the building in the most realistic way with the walk-through command offered by the software (Autodesk Revit, 2018).

The structural elements in the CAD system are generated with fixed geometries. However, the geometries of the structural elements in the BIM system are created within the framework of specific rules and parameters. These parameters can be predefined inside the program, or the designer can define and edit required parameters

during the project process. The geometric and non-geometric properties of the building elements are determined and expressed by the parameters (Eastman et al., 2011, p. 31). These parameters determined by the designer at the beginning or in the process establish the relationship between the elements in the project. Parametric design is constituted for the function and manufacturability of the design with some project information added to the model. This information provides the designer with geometric and non-geometric attributes of intelligent objects.

In the Parametric model, specific numerical algorithms are determined by the designer. All the building elements in the project are generated with parameters and thus the parametric model is created in the final (Designingbuilding, 2020). In the parametric model, the relationship between building elements such as the suspended ceiling and the floor can be shown as examples. When the floor level changes, the position of the suspended ceiling associated with it changes according to the floor, with the mathematical algorithm determined between the lower level of the floor and the position of the suspended ceiling. The parameters are assigned to the element in the project. However, in a numerical change, all suspended ceilings of the same type in the project vary according to the algorithm determined by the designer (Designingbuilding, 2020).

2.3.1 Object-Based Parametric Modeling

Object-based parametric modeling is the modeling methodology designed in Revit software. It can be said that the object has not a fixed geometry and features to be modeled according to this modeling system. Even the object is revealed by entering non-geometric information (See Fig.2.15). The object can be changed as required by design according to the parameters and rules determined by the designer (Eastman et al., 2011, p. 25).

Each element in the project has its own geometric and non-geometric features, and these are expressed with the created parameters within the scope of the BIM project. However, generating these elements as separate models with parameters in the Revit program is insufficient to explain the BIM system. In addition, all elements in the project have to belong to a family and class. These family types are categorized according to building elements such as Wall, floor, window, door in the Revit software. Building elements are categorized under family types, and each element's

feature is shaped according to the family type's context. Editing geometric or non-geometric values inside the family context changes all the elements belonging to that family type (Eastman et al., 2011, p. 41). In case the wall thickness is changed in the context of the walls produced with the same wall family type and having the same layers, the thickness of all walls belonging to that family type in the project changes simultaneously.

In the architectural project, the object to be designed in the model can be 3D walls, floor, stair, railing, also in 2D, it can be annotation, tag, title blocks. All 3D or 2D elements to be added to the project must be family. In an ordinary 3D modeling program, the objects in the design are individually handled and modeled. However, families are upper categories that objects need to be linked to in Revit. Each object has the properties of the family it belongs to. Any change made within the family, all the objects belonging to the family are affected by this change.

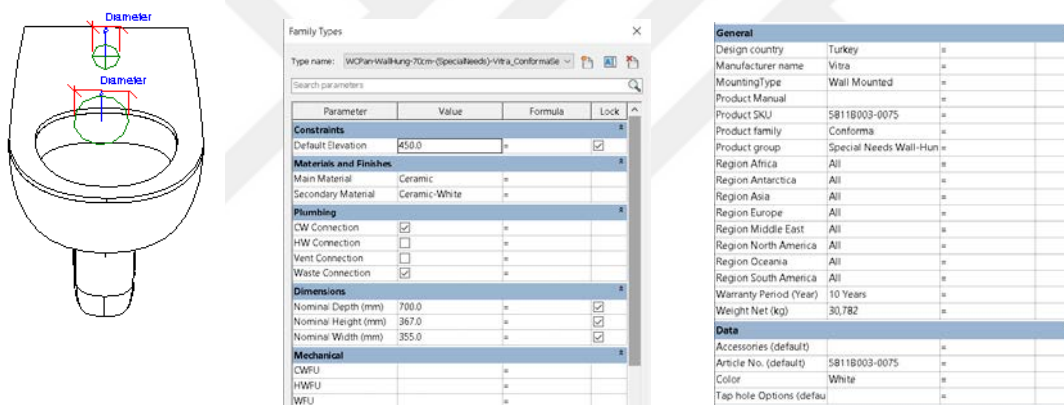


Figure 2. 15: Geometric and non-geometric parametric data of the water closet of Vitra. Source: BIMobject (2011).

2.3.2 Family Types

Family is an element that can create an unlimited number of types within the limits of predetermined parameters by a designer in Revit (Aubin, 2016, p. 477). Families are necessary components to model architectural elements such as walls, floors, stairs, windows, doors, and families can have more than one type. For example, different wall families can be found in the same project. These wall families can be separated in terms of size, material, brand or other parameters. The change made in a family is assigned to the type in the entire project and affects all walls which belong to the related type (Learning Revit, 2013).

In parametric modeling, the designer focuses on designing families within the entire project, not just on individual modeling of objects. Forms are created by adjusting the rules and parameters determined by the designer. The dimensional properties of the forms in the project, such as length, width, depth and angle can be changed within context (Eastman et al., 2011, p. 41). The relationship of each designed element with other building elements is also designed in Revit. In this way, the changes made in the context affect not only the building element of that family, but also all the related elements, just like the real construction field. The fact that the interaction between the 3D building elements in the software is the same as in real life enables the problems to be determined in advance and shortens the project time.

There are different family types available in the Revit as an alternative to the designer. Family types are divided into three as System Family, loadable Family, in-Place Family (Autodesk, 2018). The usage of family types may vary depending on the originality, flexibility and level of detail.

System family is a family type that is the default in Revit software. This family type cannot be added to another project or deleted from a project by the designer. New family types can be produced according to the project requirements via predefined 3D and 2D system families; these are custom elements created by the designer. System families can neither be uploaded from an external file to Revit nor exported to another file. Basic elements in the construction site such as wall, roof, floor, ducts can be given as an example of this family type (See Fig.2.16).

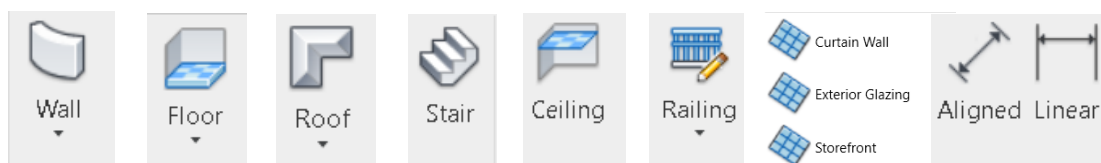


Figure 2. 16: System family elements in Revit. Source: Revit user interface.

It is a family type that can be loaded into the project from the Revit library or an external file. Unlike the System family type, the Loadable family type can be deleted from the project, customized according to the designer's request, and saved in an external file. Loadable families can be 3D and 2D. Windows, doors, furniture families are examples in 3D; title blocks and tags are examples in 2D (See Fig.2.17).

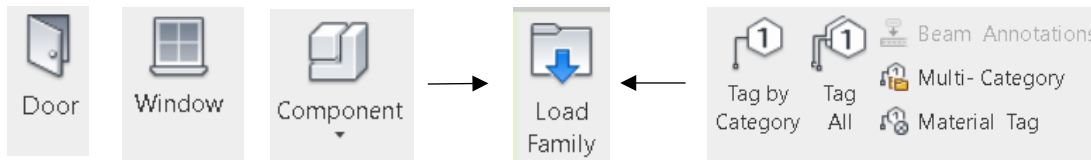


Figure 2. 17: Loadable family elements in Revit. Source: Revit user interface.

Websites such as BIMobject contain the products provided by the manufacturer companies for usage in BIM design with different file formats. Models taken from these sites are loaded into the project as a loadable family, and it is loaded into the project in its actual dimensions with the context provided by the manufacturer. Loadable families can be uploaded to the project or transferred to another Revit project.

In-place family is a project-specific family type, and unique components are created within the project. It cannot be transferred to an external file and cannot be loaded into the project from an external file. The flexibility in 3D modeling programs is mostly like in-place family type. Generating irregular shapes in the project with in-place family type is faster and easier than compared to other family types. In this way, non-standard or project-specific custom elements are produced with the in-place family (See Fig.2.18). When modeling with the in-place family, one of the system family categories such as wall, floor, generic model, ceiling is selected for each element. The element to be modeled with the in-place family has the system family category's properties.



Figure 2. 18: In-place family elements in Revit. Source: Autodesk (2012).

Due to the fact that in-place families are more flexible than other family types and the ease of producing shapes, it provides convenience to the project in irregular design scenarios. However, when this family type is used to produce all the elements in the project, it does not differ from an ordinary 3D modeling program. For this reason, it is more accurate to use it to produce unique elements specific to the project in terms of BIM methodology.

2.3.3 Adaptive Components in Revit

Complex, dynamic designs or elements can be generated and quickly edited with adaptive components in Revit. Elements that are different geometries and adaptable to the project can be added to the design without adding parameters each time, and most importantly, they can be intervened manually in the project with the aid of the adaptive family. Adaptive components are used when the family in the project needs to be adapted to different positions (Molinos, 2016).

Adaptive components can be created through adaptive families. Adaptive families can be loaded from the family editor as a loadable family or added to the project as an In-place family. For this reason, it can be said that adaptive families include two family types: loadable family and in-place family. Adaptive components can be created in Revit with two different family types: Metric Generic Model Adaptive Family and Metric Generic Model Pattern Based Family. Some features distinguish adaptive components created with adaptive family types from regular components. Regular family is used in a project that can be controlled from a single point by determining some parameters and rules. On the other hand, adaptive families have more than one control point, so that the family can take shape according to the location of the control points (See Fig.2.19).

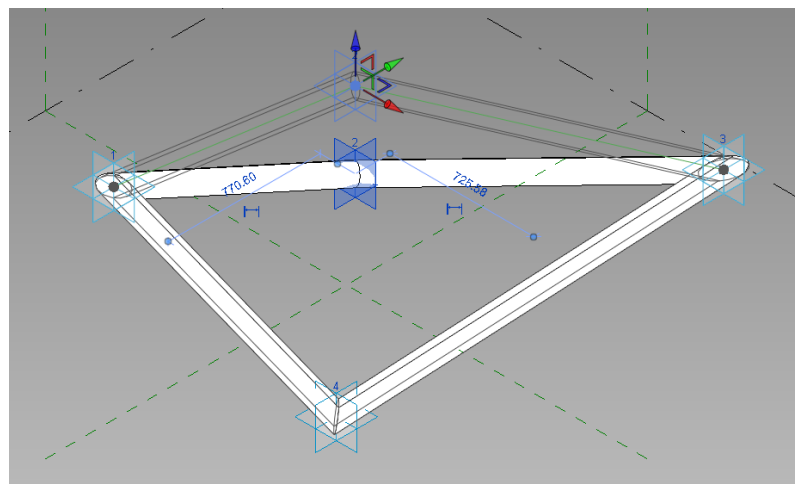


Figure 2. 19: Adaptive family control points. Source: Author's archive.

Adaptive components can be constituted in a variety of ways within Revit. As mentioned before, it can be created with Adaptive Family and Pattern-Based Family types and uploaded to the project. Apart from these, they can be loaded into the mass

category or directly into the project (Molinos, 2016). In addition, adaptive components created with the Adaptive family can be loaded into another adaptive family.

Adaptive components are generated by combining multiple adaptive points and take shape with these points (Autodesk, 2020). The geometric form created with the modeling tools in the adaptive family moves together with the adaptive points. Adaptive points can move in the x, y, z axes, and the geometric object formed by the points coming together takes shape according to the movement of the adaptive points (See Fig.2.20). Since adaptive points are the reference of the adaptive components to be created, the numbers and locations of adaptive points are of great importance. When adaptive points are placed in the family, they are numbered as default by Revit, and their numbers can be changed by the designer. However, it should be taken into the consideration that if the order of adaptive point numbers is changed, the order of placing the components in the project will also change.



Figure 2. 20: Movement of adaptive points. Source: Molinos (2016).

The adaptive components are located into the project according to the predetermined work plane with position and orientation. For this reason, before starting modeling, the work plane must be arranged (See Fig.2.21) (Aubin, 2016, p. 753).

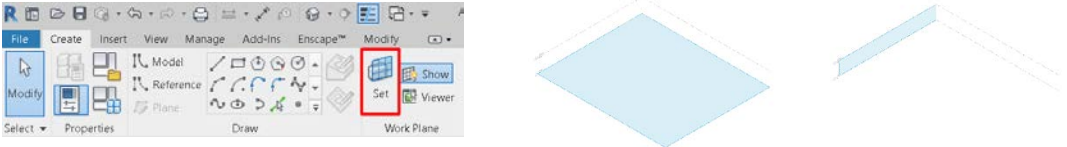


Figure 2. 21: Determination of work plane. Source: Revit user interface.

2.3.4 Metric Generic Model Pattern Based Family

In this thesis, the problem of modeling deteriorated structural-architectural elements of historical buildings as smart objects in the Autodesk Revit software is discussed. Accordingly, the modeling and production possibilities of the Revit platform have

been researched and evaluated. In the direction of the experiments performed on a sample masonry wall with the non-standard stone arrangement, it was tried to reach the result that best solved the problem. The method determined as a result of the evaluations on the sample masonry wall will be executed on a case study. The historical building project selected as a case study will be produced in Revit with smart objects from beginning to end. In this section, two different methods for modeling deteriorated masonry stone wall as smart objects in the Revit program will be explained. The first of these is the family type named "Metric Generic Model Pattern Based Family". "Metric Generic Model Pattern Based Family" is one of many different family types listed above that exist in the family editor part. In this section, there are family types to produce the building elements to be created other than system families. The required base system to produce family types is included in the Revit software by default.

It is possible to quickly and easily determine a pattern and model the masonry stone wall in Revit with the generic model pattern-based family (See Fig.2.22a). In this method, the pattern grid identified in the family and the element adapted to the pattern grid is modeled. Subsequently, it can be included in the project with in-place mass.

A new family file is opened by selecting "Generic Model Pattern Based Family" from the family editor in Revit. The Generic model pattern-based family includes adaptive points, reference lines and predefined tile pattern grid by default (See Fig.2.22b).

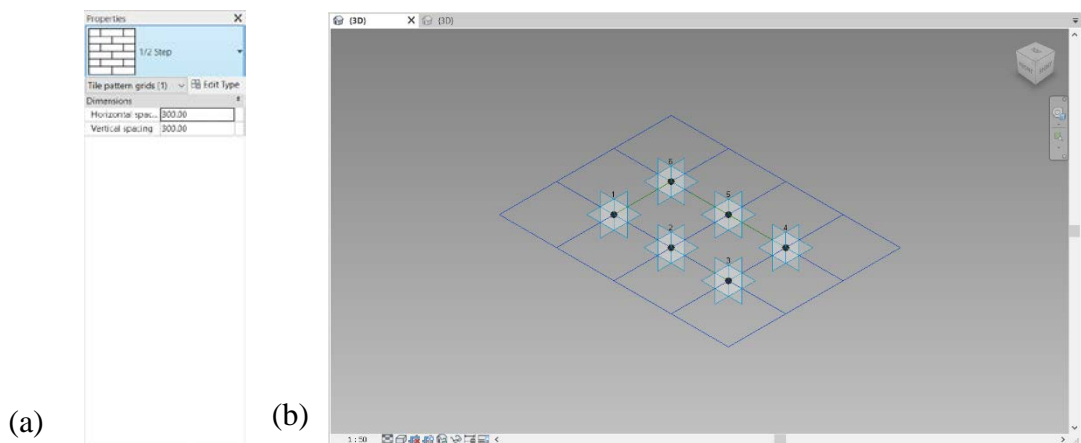


Figure 2. 22: (a) Selected pattern types, (b) Predefined adaptive points, reference lines and pattern grid. Source: Revit user interface.

The tile pattern grid that comes by default in the family is the host of the adaptive points, and when loaded into the project, the modeled object is arranged according to this pattern grid. One of the other pattern types included in the Revit can be selected or the vertical/horizontal ranges of the grid can be custom created (See Fig.2.23a). In the family, the element to be adapted to the pattern is created using the "create form" command with the predefined or re-created reference lines (See Fig.2.23b).

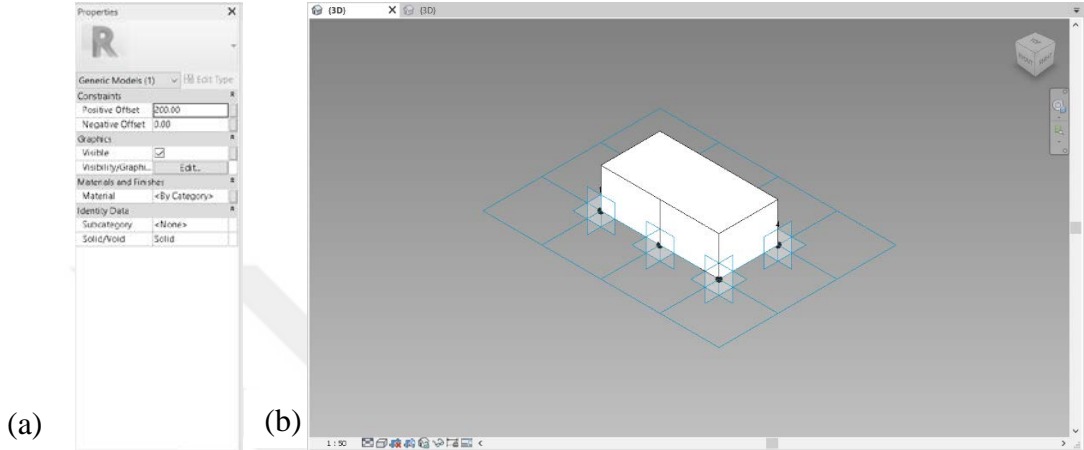


Figure 2. 23: (a) Custom pattern types, (b) Creating form with reference lines. Source: Revit user interface.

A single stone of the masonry wall is created in the generic model pattern-based family, and it is loaded into the mass model in the main project with the "load into project" command. Generic model pattern-based family can be added to the project with mass modeling, which is generally used to produce free geometric forms. The surface of the wall is created by drawing the surface in the mass model (See Fig.2.24a). In this section, the form suitable for the project can be obtained through modeling tools. The points on the edges and corners of the surface can be moved to the desired form (See Fig.2.24b) by dragging reference points or toggling coordinates (See Fig.2.24c).

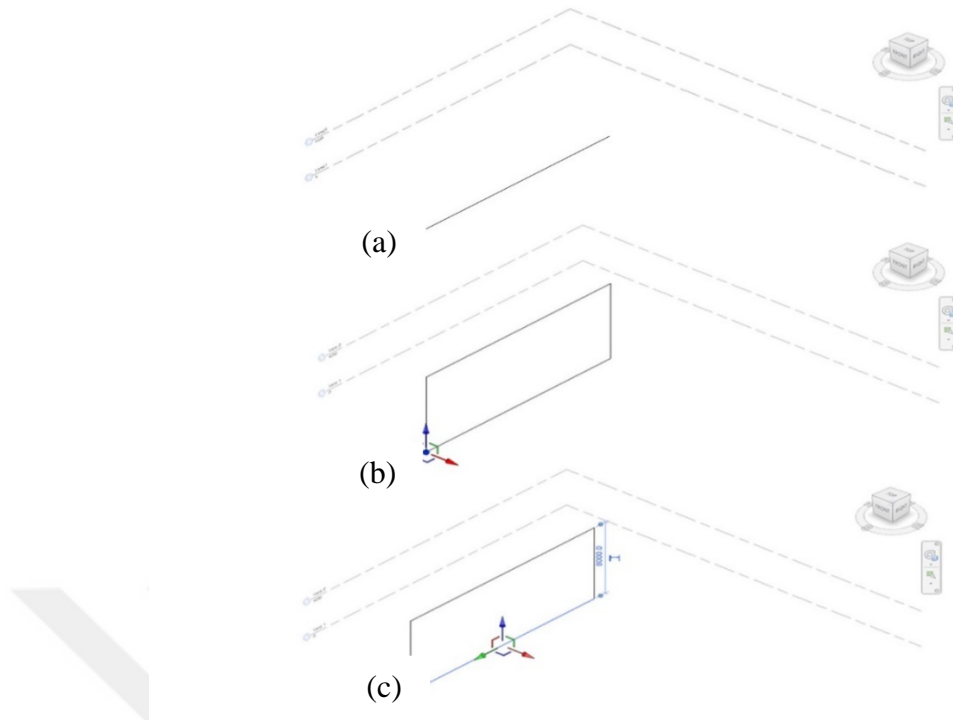


Figure 2. 24: (a) Creating surface from model line, (b) Dragging reference point of surface corner through x, y, z coordinates. (c) Dragging edge of surface through x, y, z coordinates. Source: Author's archive.

The created surface is divided into grids with the command "Divide Surface". The same pattern grid selected in the family is also found in mass modeling. The new family created under the tile pattern grid type selected in the generic model pattern-based family is displayed (See Fig.2.25). After selecting this family type, the surface becomes 3D with the numerical values entered in the program.

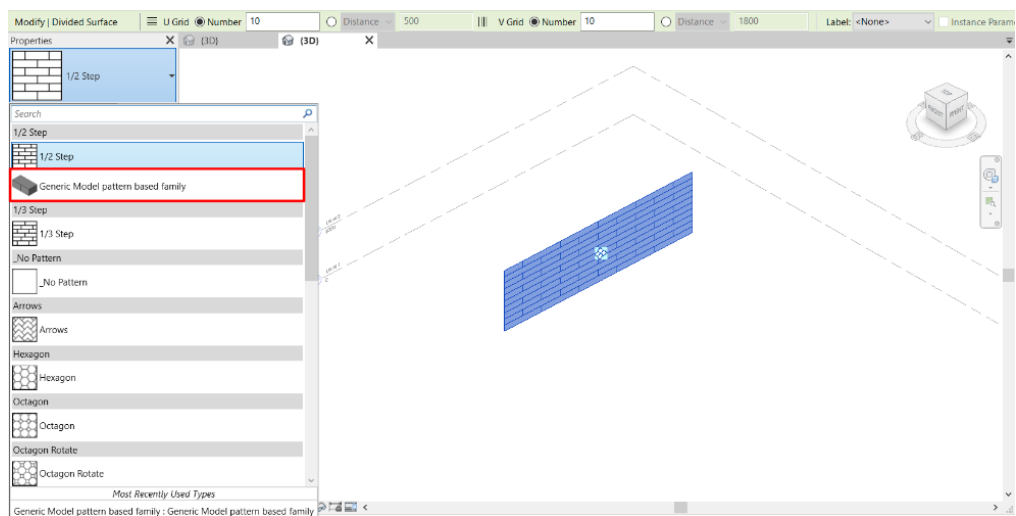


Figure 2. 25: Generic model pattern-based family in the tile pattern grid. Source: Author's archive.

The frequency of the stones can be changed, rotated, offset, and the volume of a single stone can be calculated by entering values in the U grid and V grid section of the properties (See Fig.2.26). In the object-based parametric modeling, the dimensions, material, location type data of each object exist in the program, and the necessary data can be obtained accurately and quickly. For instances, the volume value of the whole masonry stone wall can be obtained according to the stone sizes entered in the family.

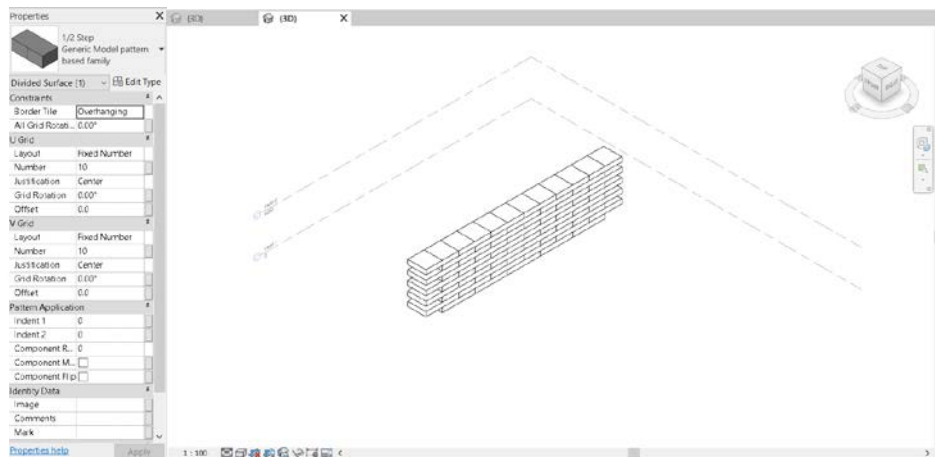


Figure 2. 26: Custom Geometric Changes in Properties Section. Source: Author's archive.

According to this method, the 3D model of masonry stone wall can be constituted quickly in Revit. The height, width, depth values and geometry of the whole masonry wall can be determined by creating a grid pattern. However, although the model of the massive masonry wall of the historical structure is in accurate dimensions, the size of each stone inside the wall is not actually the same. The stones separated from each other in the real building in terms of measurement and even materials. For this reason, these stones must be different in the 3D model. The stones of the masonry wall have the same properties in the model created with the generic model pattern-based family. In this case, the most accurate modeling cannot be obtained.

2.3.5 Metric Generic Model Adaptive Family

Generic model adaptive family is another method used to model non-standard masonry stone walls of historical buildings in Revit. In this method, the stone module to be transferred into the project is modeled with adaptive points in the family. Subsequently, it is integrated into the project with in-place mass modeling.

A new family file is opened by selecting “Generic Model Adaptive Family” from the family editor in Revit (See Fig.2.27). In the generic model adaptive family, there is no default element other than the working work plane. In this family type, the designer must add adaptive points and reference lines into the work plane. The stone module of the building wall to be adapted to different dimensions is modeled with the adaptive points added by the designer.

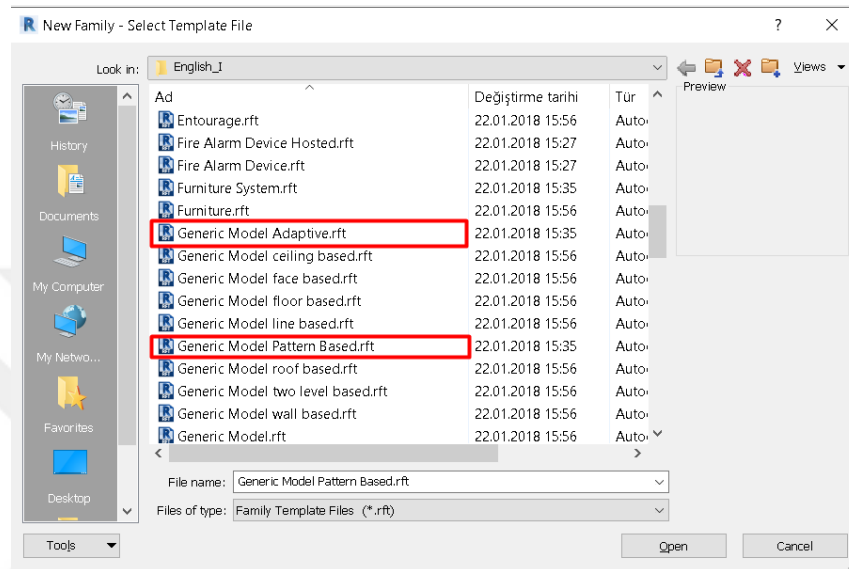


Figure 2. 27: Selecting “Generic Model Adaptive Family” and “Generic Model Pattern Based Family” from the family editor in Revit. Source: Revit user interface.

As mentioned before, the order of putting the adaptive points on the work plane is essential. When placing the stones to be adapted to the project, it is necessary to place them in the same order as when creating in the family. If it is not placed in the same order, Revit does not create and delete the object from the project by giving a warning. After determining the work plane, it is crucial to converting the ordinary points placed on the work plane to the adaptive point with the "make adaptive" command (See Fig.2.28a). A reference line is used to connect adaptive points so that the created object can move simultaneously as the adaptive points move (See Fig.2.28b). With the "3D snapping" command, a loop is created between the points and a 3D stone model is produced with reference lines (See Fig.2.29). The object's dimensions are entered in the generic model adaptive family and finally loaded into the main project.

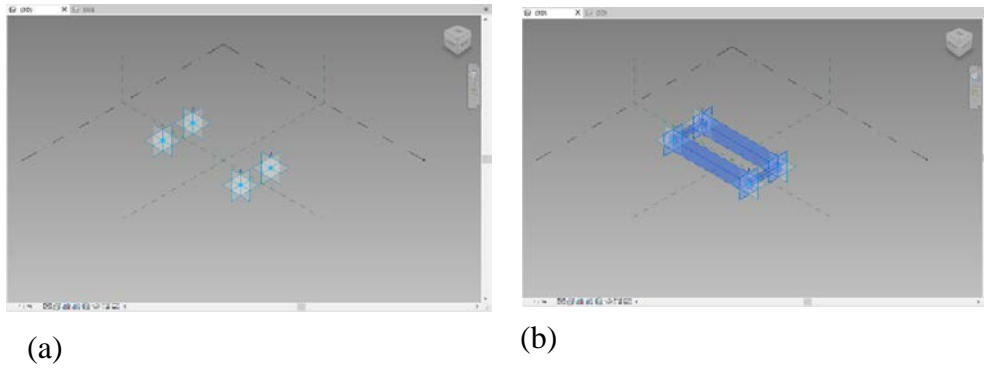


Figure 2. 28: (a) Adaptive points. (b) Reference lines. Source: Author's archive.

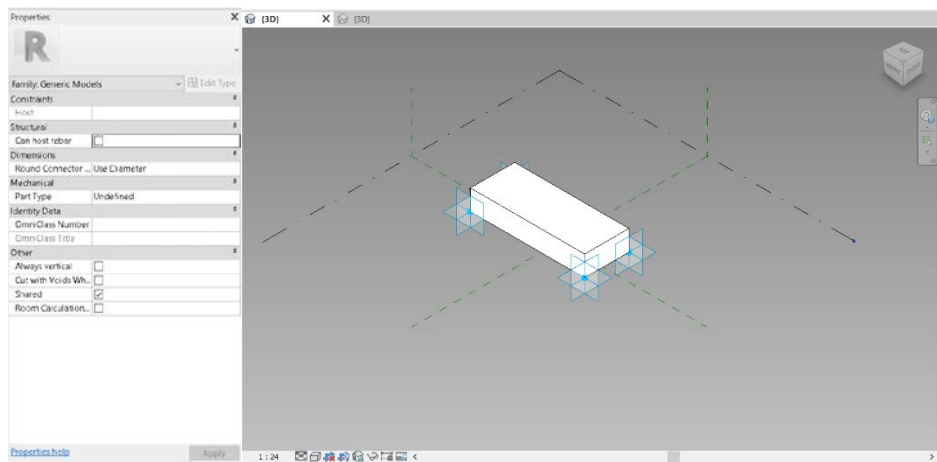


Figure 2. 29: 3D stone model produced with reference lines. Source: Author's archive.

Since there is no predefined pattern grid in the generic model adaptive family, a pattern is created in the main project, and the stones are arranged according to the specified pattern. For this reason, it is necessary to create a pattern with in-place mass modeling in the main project. As in the generic model pattern-based family, a surface is created in mass modeling. The wall drawings obtained from the historical building are transferred to Revit for the adaptive families, which will be settled according to the masonry stone wall partitions of the historic building. Masonry wall partition drawings are placed on the surface created in mass modeling. The surface is initially produced in mass modeling because it will create the host of the points, but then it is deleted (See Fig.2.30).

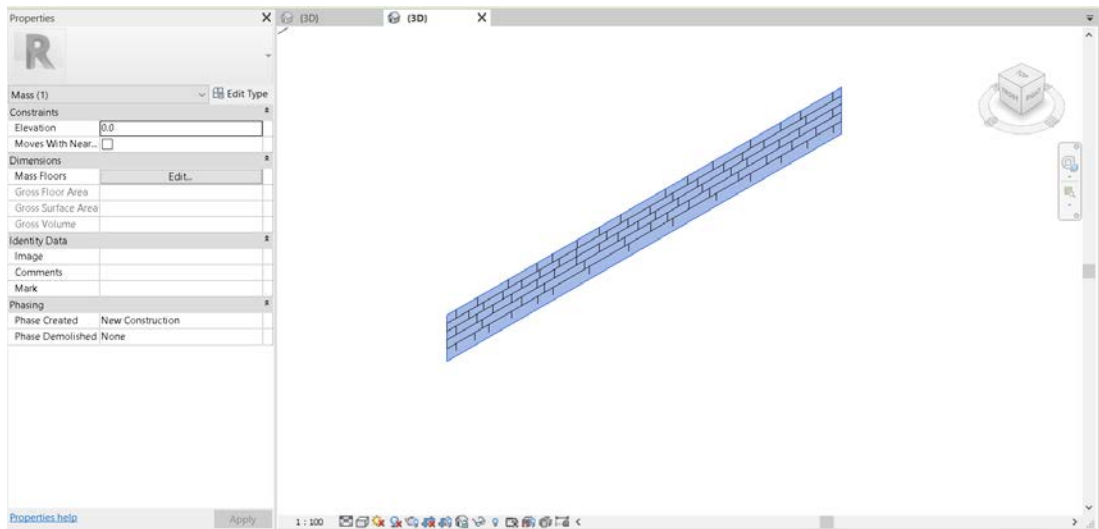


Figure 2. 30: Mass surface which is host of points. Source: Author's archive.

In mass modeling, model points are placed at the stone intersections on the surface with reference to the 2D masonry stone drawing (See Fig.2.31). The stone module generated in the generic adaptive family is selected by choosing the "place a component" command and placed in points in the order specified in the family (See Fig.2.32).

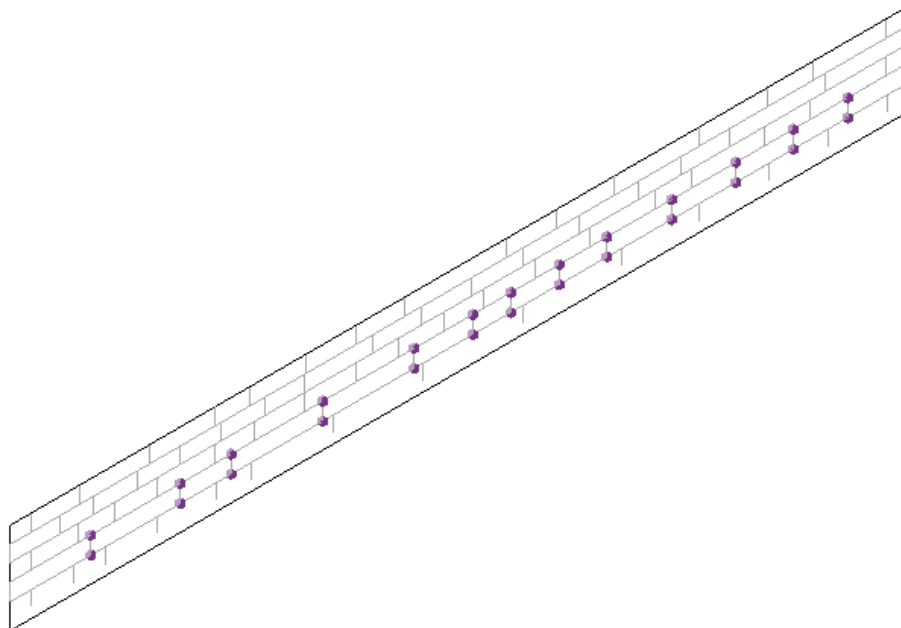


Figure 2. 31: Model points are placed on stone intersections. Source: Author's archive.

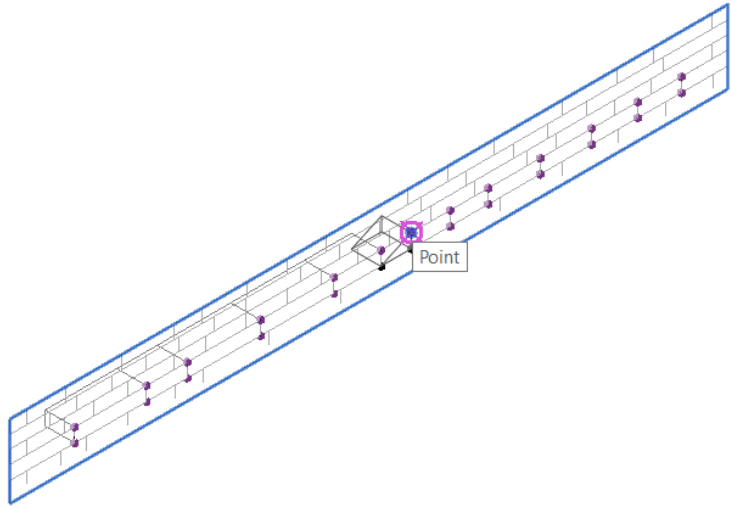


Figure 2. 32: The stone module is placed sequentially on the points. Source: Author's archive.

After the Adaptive family stone module is placed on the surface, all the reference points are selected (See Fig.2.33b), and the tick mark in the "driven by host" option is removed from the properties section (See Fig.2.33a). In this way, the stones become connected among themselves through adaptive points and in a change to one, the stone connected to it also takes shape (See Fig.2.34).

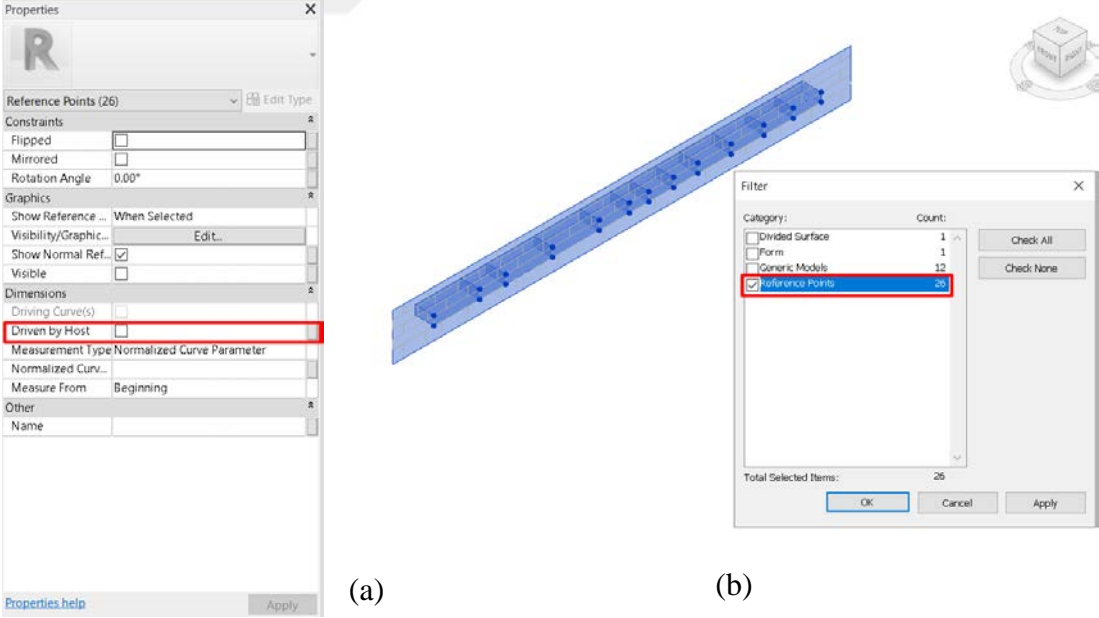


Figure 2. 33: (a) Unchecking driven by host section, (b) Selecting all reference points in the project. Source: Author's archive.

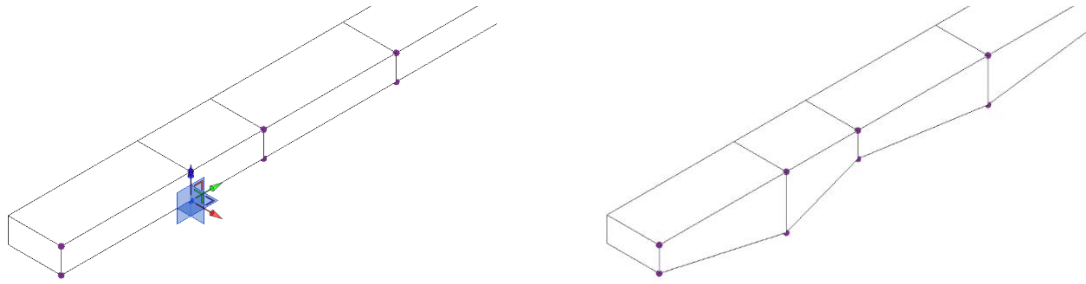


Figure 2. 34: Stone modules moving in relation to each other. Source: Author's archive.

Each stone of the masonry wall in the historical building is modeled as 3D separately in Revit with this method. Apart from the fact that the dimensions of the masonry stone wall are the same; the dimensions, shapes and materials of each stone in the wall are also the same as in the real building. Although the modeling duration is longer than the "Generic Model Pattern Based Family", the historic building masonry wall created with the "generic model adaptive family" has the most realistic model shape with the entered specific details of each stone.

It is not important that the stones created with the generic model adaptive family differ from each other in material or size. An individually editable system methodology has been designed with the aid of adaptive families in the project. With this system, each piece of elements in the project is interconnected. Therefore, the change to be made in one of them affects the other stones associated with that stone, just as in the real historical building.

It is possible to model the stone elements of the historical building that differ in time in the most realistic and 3D way with the generic model adaptive family. An ID can be defined for each stone by modeling each stone of the historical building wall separately in Revit. The features of non-standard stones can enter the program. The volume of each stone in Dimensional, the image of each stone, the notes of the stone to be recorded, and ID can be entered as identity data. Plan, section, view, perspective, orthographic 2D drawings can be obtained from a 3D model. The photos taken from the real structure can be uploaded to each stone separately, and the visual schedule can be obtained from the model.



3.CASE STUDY

This thesis aims to digitize and document structural building elements as smart objects within the HBIM system. However, historical building elements have been non-uniformly deteriorated over time. It is necessary to obtain the current building elements information of the building to digitize these data. This system is traditionally provided by restitution projects. Restitution projects of historical buildings are created manually by obtaining data from the building and converting them into 2D drawings. The restitution project of the historical building will be used as an underlay within this project scope, but this drawing also includes damaged structural elements. Within the scope of the HBIM model, it is not feasible to model each deteriorated structural element separately. The reason for this is that each element deteriorates geometrically over time. This thesis focuses on modeling the non-uniform elements with regular geometries rather than modeling the geometries of the deteriorated elements of the historic building. In other words, it focuses on digitizing historical building elements with proper geometries. This study is located in a different part from the applied HBIM workflows. However, restitution project modeling was preferred within the scope of this thesis in a short time to use time and resources accurately. Also, this study contains new clues for future studies of HBIM with non-uniformly elements.

In the scope of the thesis, different methodologies have been tried to model the non-uniform stone sequences of deteriorated historic masonry structures in Autodesk Revit software. The masonry stones of an actual historical building will be modeled with the methods studied in the Revit program to scrutinize the generic model adaptive family method on a real case. Thus, the masonry stones of the historical structure determined as a case study will be modeled by using the "Generic Model Adaptive Family" method among the studied methods. The historic building, which will be modeled in the Revit program with the "Generic Model Adaptive Family" method, is an arch structure from the Roman period named Anavarza/Anazarbus Triumphal Arch.

3.1 Anavarza/Anazarbus Triumphal Arch

The HBIM model of the Anavarza/Anazarbus Historical Triumphal Arch will be constituted using the methods determined within the scope of this thesis. The scope of this thesis is the creation of masonry wall models of historical structures with stone material using adaptive family types. In this process, in addition to the creation of only a 3D model, the whole process that ensures the creation, transfer, use and storage of all geometric and non-geometric data of the building elements to be modeled with smart objects will be clarified within the scope of this thesis.

The HBIM model will be created with the historical, cultural and architectural values of the ATA. The restitution studies of the ATA continue nowadays by preserving these values. Besides, The Triumphal Arch entered the UNESCO World temporary heritage list in 2014 due to its historical and architectural value. The necessary project studies continue to be included in the UNESCO World Heritage Permanent List (KTB, 2014).

Anazarbus ancient city located in Adana province, Kozan district, Dilekkaya neighborhood. Anavarza Triumphal Arch is located 28 km south of Kozan district (Gough, 1952, p. 85). It is located in the middle part of the Pyramos River in the ancient period, which is now known as the Ceyhan River in the Cilicia region. Anazarba (Anavarza), which is located next to a sizeable marble-like mountain, is located in the middle of the Ceyhan plain (Kadioğlu, 2013, p. 239). There is no specific notice that it existed before the 1st century BC. Since the ancient travelers do not spend much time in this region, there is not much data about the historical arch except general information. The reasons for this are bad weather conditions, an illicit population, and lack of communication (Gough, 1952, p. 85). Access to the ancient city of Anazarbus, located in the northeast of Adana province, is provided by passing through the Dilekkaya neighborhood/village. The ancient city is located on the southwestern foothill of the mountain, which is the last extension of the Taurus Mountains. While mountains bordered the ancient city on the eastern facade, it also bordered by the fortification walls that are still visible today on the southern, western and northern facades (Kadioğlu, 2013, p. 239).

Anazarbus Ancient City has hosted many different civilizations due to its location. It is the largest ancient city in Anatolia with 4000 acres of land. The ancient city of Anazarbus, established in the 1st century BC by the Romans, contains structures with

different functions. There is a triumphal arch, colonnaded street, mosaics, churches, necropolises, ancient theater stadium and coliseum in the ancient city. There is a triumphal arch with three entrances at the ancient city entrance on the south facade within the borders of the ancient city of Anazarbus surrounded by the walls. There is a colonnaded street of about 1750 meters in the middle of the city. This street extends in the north-south direction and is 34.8 meters wide. Also, it has the characteristic of the widest ancient street in Anatolia with this feature (Sayar&Ercan, 2008, p. 75). The Anavarza triumphal arch is located at the end of the colonnaded street extending to the south (Kadioğlu, 2013, p. 238).

The origin of the word Anavarza is assumed to be oriental, but no author, except Etienne of Byzantine, mentioned this place. Byzantine Etienne assumes that the city's name was derived from its founder or the nearby mountains. The city built on the foothills is surrounded by fortification walls, and there are four gates to enter the city. Today, Alakapı (Anavarza Triumphal Arch), located on the south facade only from the entrance gates to the city, stands as a victory gate (KTB, 2014).

The work on preparing the Anavarza Ancient City Plan started in 2004 and was completed in 2007 (Sayar&Ercan, 2008, p. 75). Triumphal arch restoration work started in 2018 and continues today. Restoration and excavation working continue for the ancient city of Anavarza, which has traces from the Hellenistic, Roman, Eastern Roman, Sassanid and Ottoman empires (AA, 2018).

3.1.1 Architecture of Anavarza/Anazarbus Triumphal Arch

Anavarza/Anazarbus Triumphal Arch was built in memory of the Roman Empire's war against the Persians in the 3rd century. In the ancient city of Anazarbus, there is an arch located independently at the south beginning of the colonnaded road extending in the north-south direction. This arch, which is now called Anavarza Triumphal Arch, is also known as Alakapı (AA, 2018). The Anavarza triumphal arch is first mentioned in the writings of Charles Texier, who came to the ancient city of Anavarza in the 1840s (p. 136).

"... The city has four gates. The gates located in west side has grand monument appearance. The width of this entrance is twenty two meters and sixty centimeters, its thickness is five meters and fifty eight centimeters in the form of a triumphal arch with three doors. The large bow in the middle is three meters and seventy five centimeters;

the width of the springs on the side is three and a half meters. There is a transverse passage inside the building, its width is two meters and ten centimeters. The last walls between the doors are decorated with columns joined in Corinthian and granite style with sitting on the skirt of the building surrounding the building. Ordre's height is six meters forty-eight centimeters. The apex consists of a frieze with a twisted leaf and decorated with sill supports. The entire top sill becomes apparent around the great arch and forms the archivolt; this example is unique in ancient monuments. This architectural style belongs to the II. Century AD... "

The triumphal arch, one of the most important elements of the ancient city, is located at the starting point of the colonnaded road (See Fig.3.1a). Measured Facade and Plan drawings of the Anavarza Triumphal Arch from 1830 contain data according to the past state of the arch (See Fig.3.2). This historical arch consists of six columns with three arches, eight legs (See Fig.3.1b). The entrance to the colonnaded road is made through the Anavarza Triumphal gate. The triumphal arch located in the south of the ancient city is a magnificent welcoming gate. While the west facade of the triumphal arch is completely collapsed, the middle and side arched passages are preserved (Özgen, 2009, p. 65).

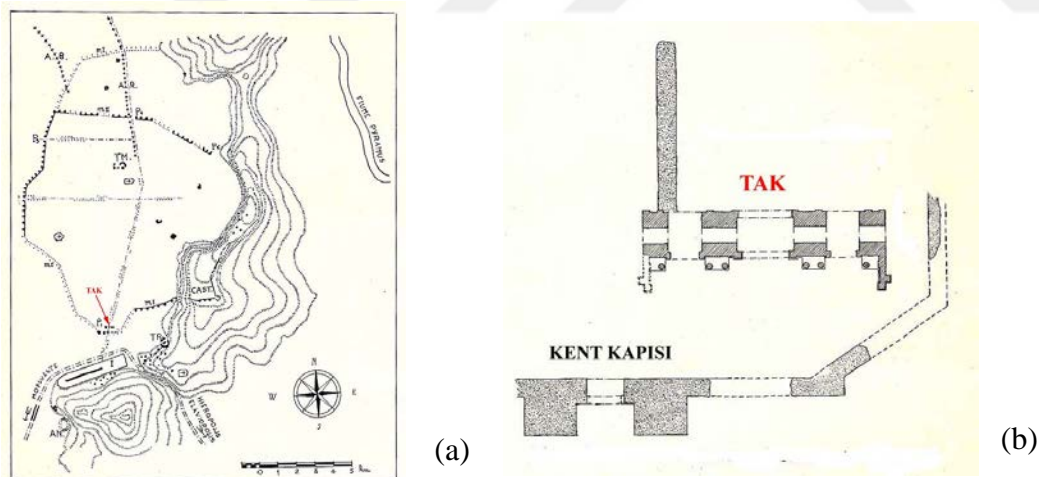


Figure 3. 1: (a) Anazarbus city plan, (b) City gate and Anazarbus arch plan.
 Source: Adapted from "Citta ellenistiche romane dell'Asia Minore: Anazarbus" by H. M. Özgen, 2009 Copyright 1957 by Verzone.

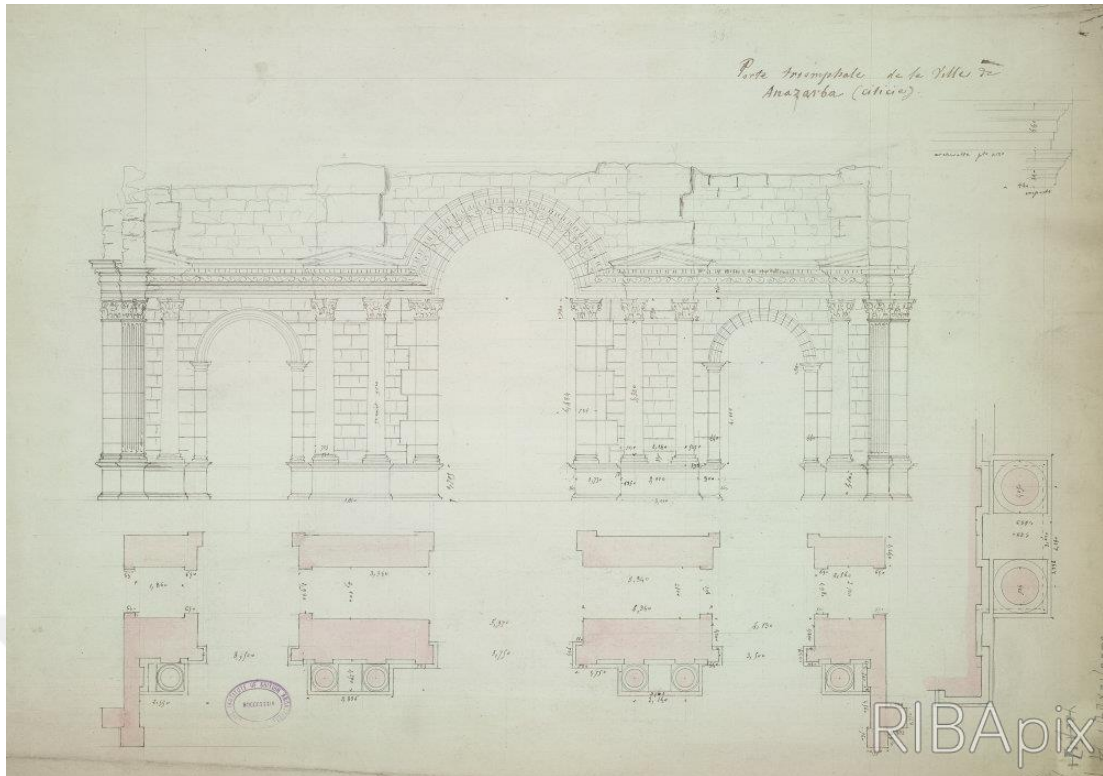


Figure 3. 2: Anavarza Triumphal Arch measured facade and plan drawing. Source: RIBA21322,1830.

It is observed that the middle arch starts from the ends of the arches on the right and left. This arch increases the emphasis on the building (See Fig.3.3). The Anavarza triumphal arch, which has three passages, also has an internal vaulted passage starting on the east and west facades. This situation is not common among the triumphal arches in Anatolia. Differences are striking between the typologies of the south facade facing the outside of the city and the north-facing inside (Özgen, 2009, pp. 65-66).

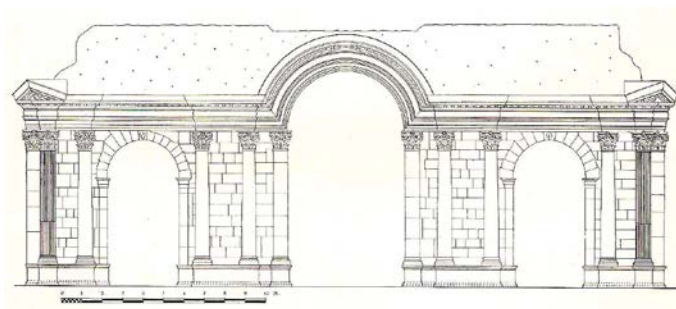


Figure 3. 3: The south facade restitution of arch. Source: Verzone, 1957.

On the south facade of the building, there are wings that make a profile to the front at the east and west ends and create a framed front area on the façade (See Fig.3.4). In addition, independent columns with Corinthian head on the south facade created an architectural composition that stands out from the building (See Fig.3.5a). There are

four columns in the independent sections with aedicula on both sides of the central arch of the south facade, with two columns on the pedestals at the junction of the east-west fronts and six columns in total on the south facade extend up to the eaves. Although the shape of the pediments on the independent sections with aedicula is undefined, they form a complete triangle. There are half pediments on the columns at the east and west joints of the building. The architrave and frieze on the south facade consist of a single block, and there are different kinds of decorations on it (See Fig.3.5b). The geison and sima in the same section are also a single block, and various ornaments are embroidered on them. When the blocks in situ located on the ground are examined, there are also geison types with different architectural features (Özgen, 2009, pp. 65-66).



Figure 3. 4: South facade east vault and east wing of arch. Source: Özgen, 2009.

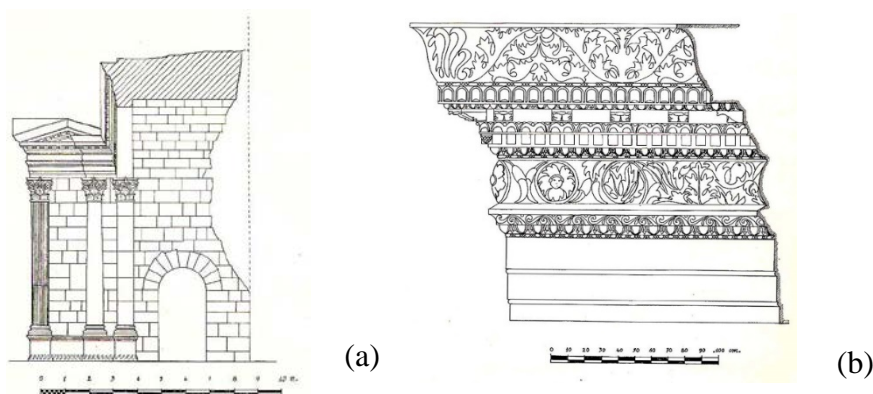


Figure 3. 5: (a) Section drawing of arch, (b) Combination of architrave and frieze. Source: Verzone, 1957.

There are no clues about the aedicula independent section traces on the north facade of the building as on the south facade (See Fig.3.6a). There are niches to the right and left of the middle arch in the north facade (See Fig.3.6b). Since the stones of the

building above the central arch of the triumphal arch could not be preserved, there is no information about the superstructure. However, comments can be made about this from the parts of the structure on the ground (Özgen, 2009, pp. 65-66). Triumphal arch restoration work started in 2018 and continues today (See Fig.3.7) (AA, 2018).

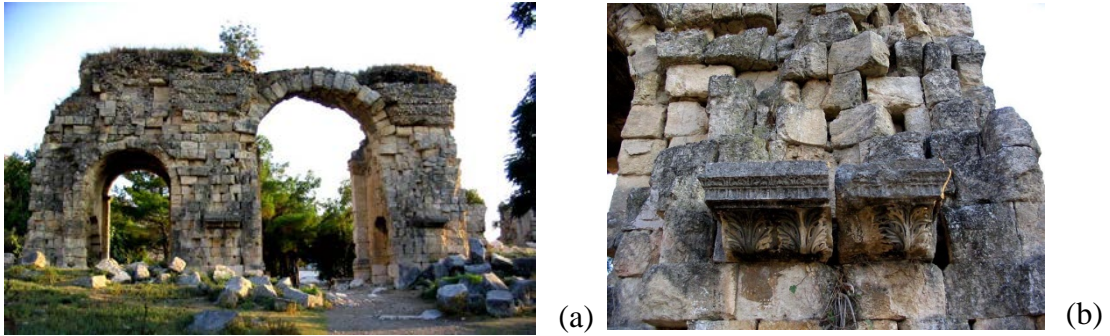


Figure 3. 6: (a) North view of arch, (b) Niche and console from the north facade. Source: Özgen, 2009.



Figure 3. 7: Restored south facade and north facade. Source: Arkeolojik Haber, 2020.

3.2 Modelling Stages of Anavarza/Anazarbus Triumphal Arch

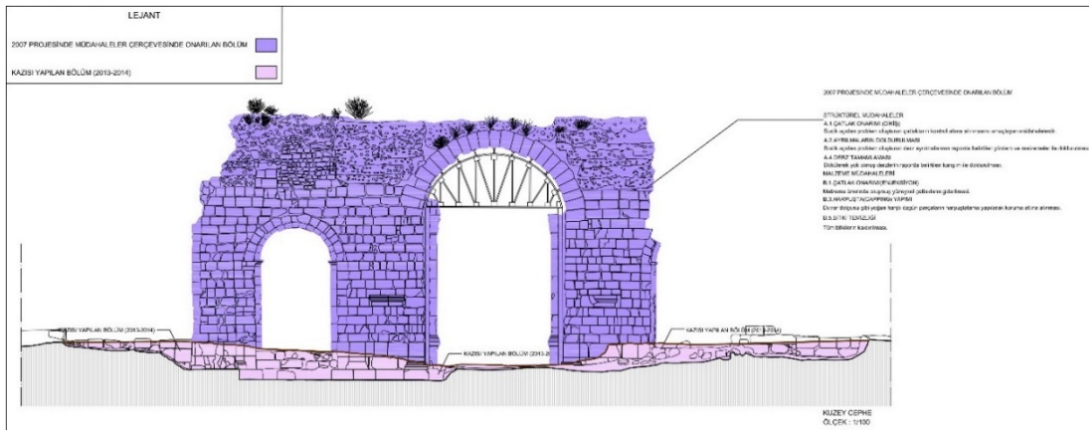
In this part of the thesis, the constitution process of the HBIM model with adaptive families in the Revit program of the Anavarza/Anazarbus Triumphal Arch (ATA) will be presented. For this, all steps taken from the beginning to the end of the project process will be supported by visuals and graphics. This application is a testwork for historical building masonry stones. For this, there are different alternatives to the suggested methods and tools used throughout the process. However, within this project's scope, the methods and tools that are considered the most accurate will be explained. There are seven intermediate steps from the beginning to the end of the modeling process. These steps will be explained in detail sequentially in these sections.

3.2.1 Analysis of 2D Drawings

It is aimed to use 2D restitution drawings as an underlay to rebuild the ATA project in Revit in this section. In the drawings, the condition and data of the building in 2007, 2013-2014 are entered as the final version. In this section, 2D Autocad drawings of ATA will be examined and analyzed.

The Autocad drawing of the ATA restitution project consists of three different sections showing the interventions of the building in different time periods. Each section contains a different kind of information about the historic building. These sections are as follows in order; "2D Drawing of interventions by 2013-2014 and 2007 year", "2D Drawing of insitu blocks, inventory blocks and undetectable blocks" and "2D Drawing of intervention and restoration decision".

The first drawing of the ATA restitution project is the 2D drawing of interventions by 2013-2014 and 2007 year. Since the drawings in the legend of this section are the as-built form of the triumphal arch, it is divided into two "the section restored within the framework of the interventions in the 2007 project" and "the section excavated in 2013-2014". The interventions implemented in 2007, comprehensive explanations and 2013-2014 excavations are marked on the plan, section and elevation drawings. It is expressed with the colors indicated on the legend (See Fig.3.8).



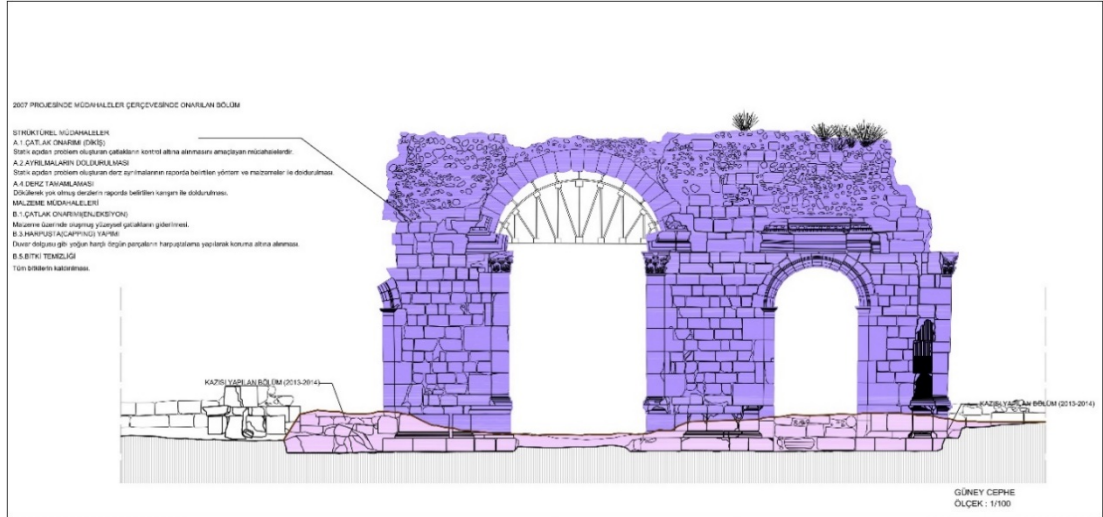
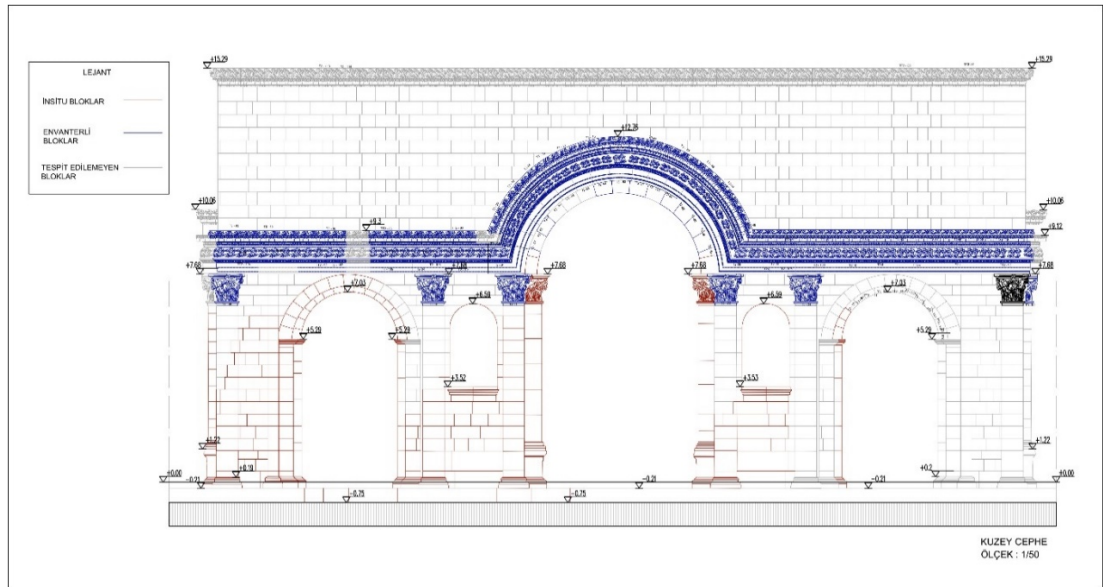


Figure 3. 8: 2D Drawing of interventions by 2013-2014 and 2007 year on north and south facade. Source: Anavarza/Anazarbus Triumphal Arch Restitution Project.

The second drawing of the ATA restitution project is the 2D drawing of insitu blocks, inventory blocks and undetectable blocks. The building elements in the drawing are divided into three parts: insitu blocks, inventory blocks and undetectable blocks in the legend. The color of each section is different, and the building elements are point out in these colors on the drawing. In the drawings in this section, the parts removed during the excavations carried out in 2013-2014 are not included in this drawing set. The building elements belonging to the inventory blocks have specific codes, and their codes are indicated on the drawing (See Fig.3.9).



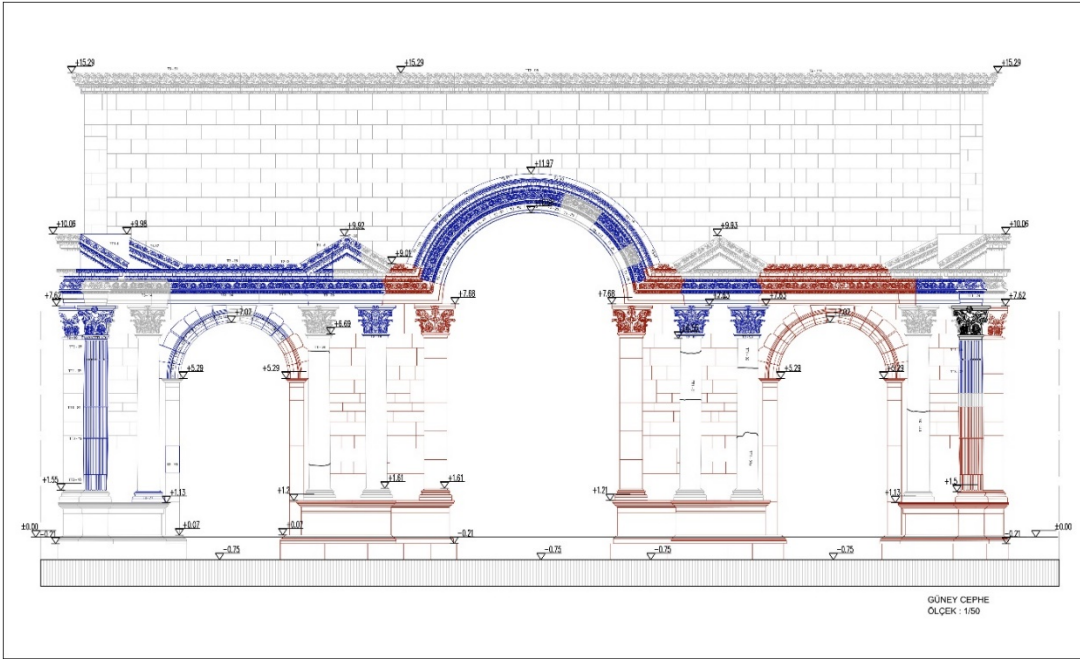
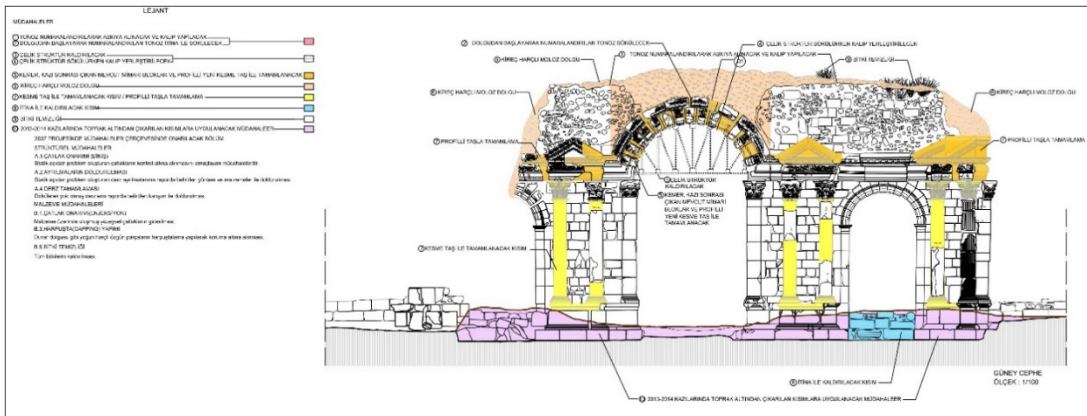


Figure 3.9: 2D Drawing of insitu blocks, inventory blocks and undetectable blocks on north and south facade. Source: Anavarza/Anazarbus Triumphal Arch Restitution Project.

The third drawing of the ATA restitution project is the 2D drawing of intervention and restoration decisions. In the drawings, there are plan drawings, north, south, east and west facades drawings, two-section drawings, ceiling plan drawings and detail drawings. The forms of the intervention indicated by numbers and colors in the legend are again indicated with color and text on the drawing.

Each intervention to be implemented in these drawings is indicated in both text and color in each drawing. The interventions detailed in this section, plan and detail drawings, the building elements are also coded (See Fig.3.10).



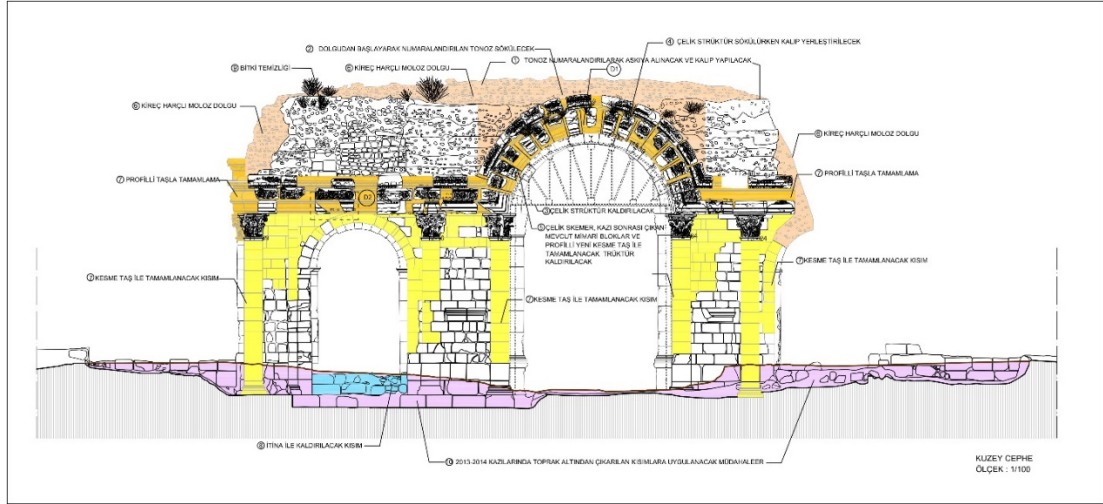


Figure 3. 10: 2D Drawing of intervention and restoration decision on north and south facade. Source: Anavarza/Anazarbus Triumphal Arch Restitution Project.

3.2.2 From 2D to Revit

In order to rebuild the Anavarza/Anazarbus Triumphal Arch project in smart objects in Revit and each building element to work holistically, specific preliminary preparations must be carried out in the 2D Autocad drawing. These preparations can be listed as follows:

1. Scale Settings
2. Unit Setup Settings
3. Project reduction and eliminating useless lines

The first step of the “From 2D to Revit” section is scale settings. In order to rebuild the ATA restitution project in Revit, the scale settings must be executed in the Autocad file. Existing building elements in the project or added later will not have the correct size in case of the absence of scale settings adjustment. In the ATA restitution project, the drawings have been scaled from a 1: 1 scale to be placed on the sheets, and therefore they are not in their actual dimensions. When the project is produced in Revit or any other program, it must be a 1: 1 scale. For this reason, the drawings should be brought to a 1: 1 scale in a new Autocad file.

The second step of the “From 2D to Revit” section is unit setup settings. The same unit setup settings used in the Autocad drawing must be specified. Before proceeding to

model in Revit, it is necessary to set the unit setup to the same unit of measure as Autocad drawing.

The third step of the “From 2D to Revit” section is project reduction and eliminating useless lines. In the project, the lines that will not work in the first phase of the drawing are deleted from the project. The reason for this is that each line increases the file size. The ornaments and complex geometries generally possessed by historical buildings add a separate file size to the drawing. For this reason, lines that will not work in the modeling phase should be extracted in the Autocad file and imported into the Revit file that way. These lines may be hatches, elevation marks, descriptions, decorative ornament lines, codes of existing stones in the drawing (See Fig.3.11).

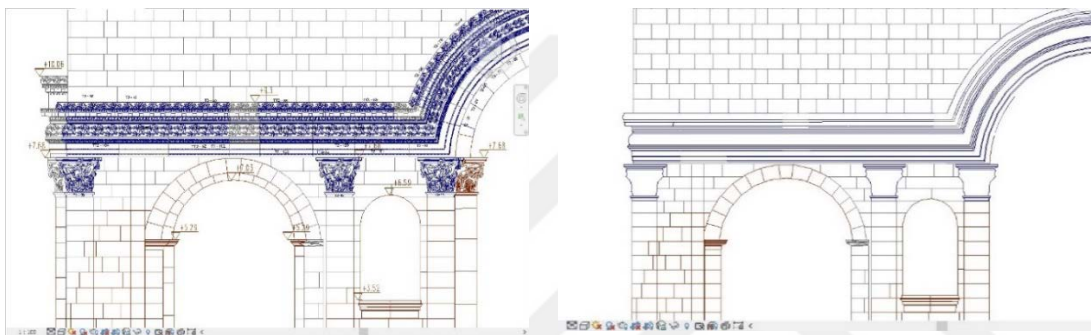


Figure 3. 11: Eliminating useless lines from 2D drawing. Source: Anavarza/Anazarbus Triumphal Arch Restitution Project.

Exploding of the dwg file in Revit will be explained in detail in the following parts of the thesis. Nevertheless, shortly after importing the Autocad file into Revit, this dwg drawing must be exploded to model it. At this point, Revit has a maximum polygon count limit, and when this limit is exceeded, Revit does not explode the dwg file. For these reasons, the Autocad drawings to be imported into Revit should be quite plain, and the lines that will not be necessary for the beginning of the model should be deleted. Otherwise, Revit warns with the statement, "imports with more than 10,000 elements cannot be exploded" (See Fig.3.12).

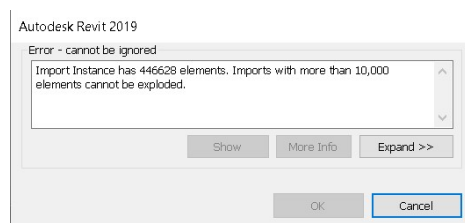


Figure 3. 12: Eliminating useless lines from 2D drawing. Source: Revit user interface.

Although the Autocad drawings are intended to be produced in 2D, or sometimes the position of some lines seems to be correct in the plan, the elevation of the lines is different from other lines, and it becomes a 3D view. In this case, the plan drawing becomes 3D, which should be 2D. This creates a situation that makes Revit modeling difficult. For this reason, it is necessary to ensure that all lines in the Autocad are flattened and placed in a single plane. Suppose the drawing is imported into Revit without executing this flatten command. In that case, Revit warns with the statement, "some numerical data within the imported file was out of range. This numerical data has been truncated". If the given warning is ignored and continued, it becomes difficult to work on the project (See Fig.3.13).

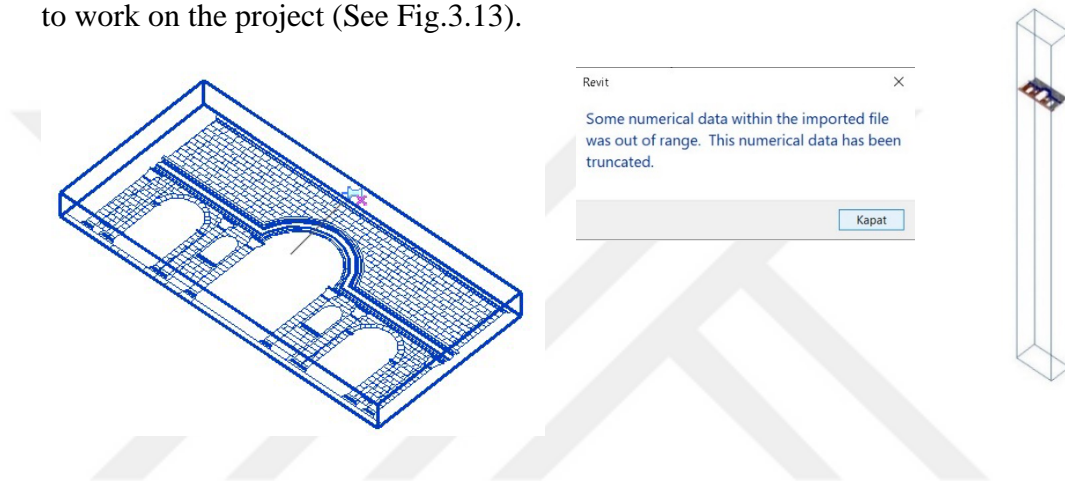


Figure 3. 13: Flattening 3D lines to a single plane. Source: Author's archive.

All details in the Autocad drawings of the ATA restitution project have been prepared in accordance with the technical drawing. However, while there is already a very complex building language and elements, and also the appearance of the elements behind in the facade drawings made it challenging to model after importing the drawing to the Revit. For this reason, it was not enough to simplify the Autocad drawings of the building from excess lines and texts. At this point, it was thought that deleting the building elements at the back of the facade drawings and importing them into Revit would cause fewer mistakes and less confusion. Thus, the elements visible on the back of the facade drawings were deleted, and the main facade structural elements were imported. In such a case, although the distance of the building elements at the rear to the façade was ignored, the position of the remaining building elements was edited in the process after the main facades were modeled. The reason for taking such a step is to reduce the margin of a mistake by working with as few lines as possible in the complete modeling process (See Fig.3.14).

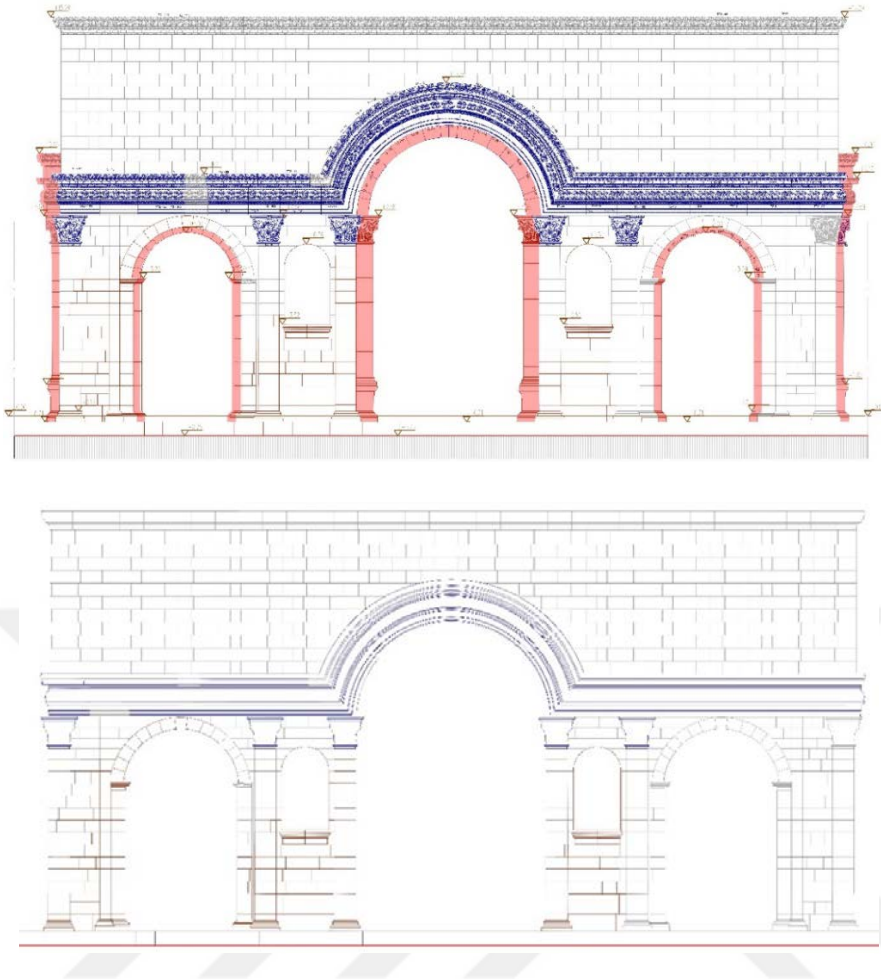


Figure 3. 14: Removing the lines located at the back of the main facade drawings. Source: Anavarza/Anazarbus Triumphal Arch Restitution Project.

In order to rebuild the ATA restitution project in Revit, after the Autocad drawings are extracted, the plan drawings and the east, west, north and south façade drawings are saved in a separate Autocad file. These drawings in a suitable format for Revit are saved as different files.

3.2.3 2D Project Data Entry into The Revit

In order to rebuild the Anavarza/Anazarbus Triumphal Arch restitution project in Revit, the survey data in the Autocad must be entered into the Revit. For this reason, necessary 2D drawing adjustments are made, and all facade and plan drawings are saved in separate files. After these adjustments, the project is transferred to the Revit program. Before importing 2D facade and plan drawings to Revit, adjustments applied in Autocad must also be applied in Revit. In this way, the drawings imported from Autocad to Revit will be compatible between the two programs. The steps to be performed in Revit can be listed as follows:

1. Unit Setup
2. Project Coordinate Setup
3. True North Settlement
4. Level Settlement
5. Importing 2D Plan and Facade Drawings
6. Bringing Together Plan and 4 Facade Drawings in the Revit
7. 2D Drawing Exploding and Grouping

The first step of the "Survey Data Entry into The Revit" section is unit setup. The unit of measure in which projects are produced in the computer environment is set with the unit setup command. In AutoCAD, the same unit value from which the projects are produced must be set in Revit. For this reason, after opening the architectural project in Revit, the unit setup must be set first. It can be set in Revit by selecting "manage tab" followed by "projects units" or direct project units can be set with the shortcut UN. Since the ATA restitution 2D Autocad project drawings are created in millimeters, the unit setup is set in millimeters in Revit (See Fig.3.15).

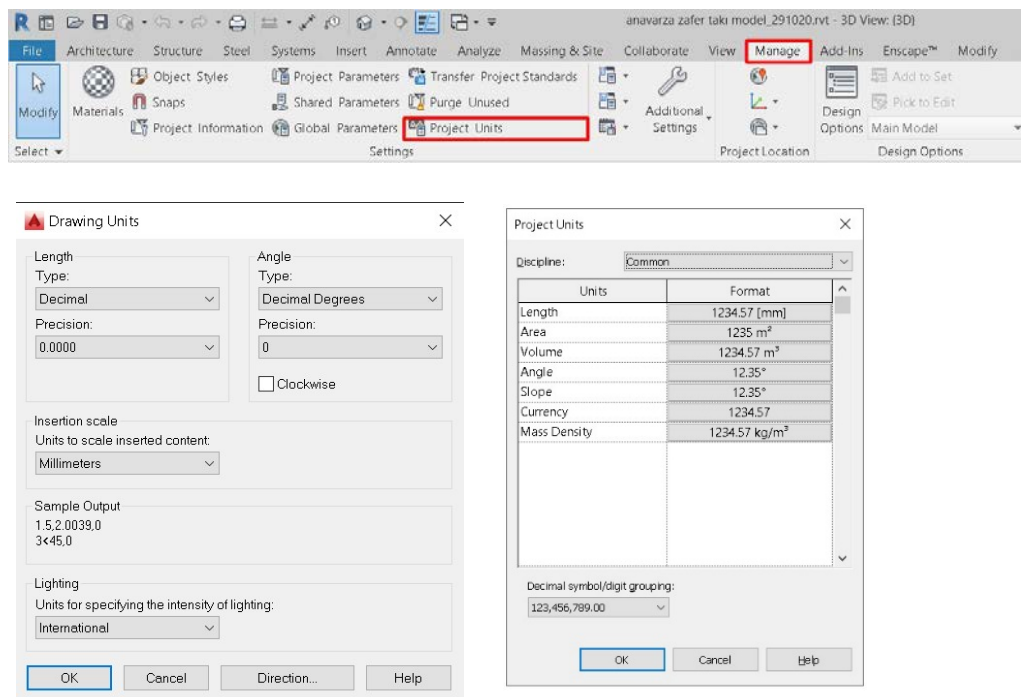


Figure 3. 15: Unit setup in the Revit. Source: Revit user interface.

The second step of the “2D Project Data Entry into The Revit” section is project coordinate setup. The positions of the points in the 2D drawing in the Autocad of the project must be the same in space as the points in Revit. In other words, it is necessary to align the origin points of Autocad and Revit drawings. In this way, the x, y, z coordinates of any point on the project will be accessible, and its effects on the intervention to be made on the project will be discussed.

Since the x, y, z coordinates of the building were not specified in the ATA restitution project. Because of this reason, the process is continued without these adjustments in Revit. However, if the main goal is to produce an as-built HBIM model with its entirety, the structure must be in the correct coordinates in space. Placing the historical building in the correct coordinates is important both create the HBIM model and obtain accurate data for future predictions. It is crucial to make future predictions such as the effects of environmental factors on the building and the conditions that occur over time to conserve the heritage building. Therefore, accurate data must be obtained from the as-built HBIM model in future predictions. Accurate x, y, z coordinates also affect the environmental data. For example, by entering the true coordinates value of the building correctly, data such as incoming sunlight, the proportion to daylight availability, and changes can be obtained. The wind direction and seasonal wind strengths of the building can be determined. The variation of the amount of precipitation the region receives by years can be calculated. Environmental factors such as sun, wind and precipitation provide data about the future of the building. For this reason, it is crucial for future predictions. In a project produced with the HBIM system, as the building elements are produced as smart objects, they contain geometric and non-geometric data. Apart from this, it also allows formulation. The change in the effect of environmental factors on each element over the years provides information about the future from today. This section will be explained in detail in the “questions for the future” section of the thesis.

Since the x, y, x coordinates of the building were not specified in the ATA restitution project, the process is continued without these adjustments in Revit. However, to explain briefly, a corner point of the Autocad drawing needs to be determined. The x and y coordinates of this point are controlled and recorded in the properties panel. Since it is a 2D drawing, the z coordinate must be zero. For the sake of precision, it would be more accurate to determine two corner points and to record the x and y

coordinates of these two points separately. After the prepared Site plan is linked to Revit, the coordinates of the same points saved in the Autocad will be entered into the program with the "specify coordinates at point" command. After this adjustment is applied, the project is placed in the correct coordinates in space (See Fig.3.16).

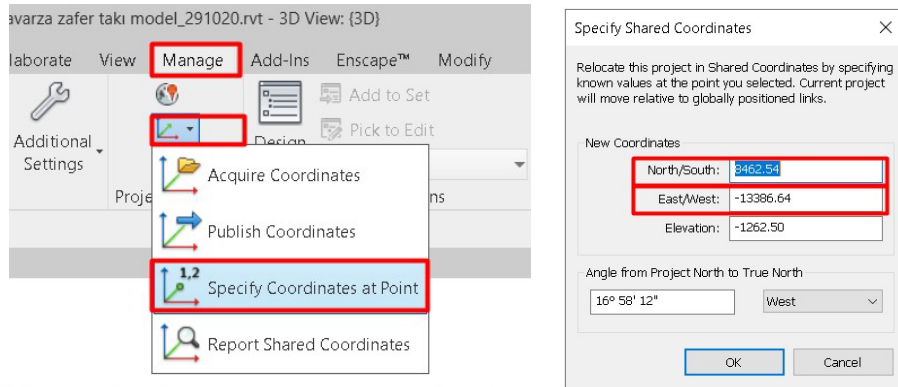


Figure 3. 16: Coordinate setup in the Revit. Source: Revit user interface.

The third step of the "2D Project Data Entry into The Revit" section is True north settlement. There is a site area where the historical building or any other project is located, and it has a northward position. The true north direction of the project is displayed perpendicularly in the site plan, and this is called the "true north" of the project. In order to understand the north direction, it is indicated by placing a north arrow in the site plan. However, while drawing on the project, the structure must be perpendicular to the computer screen. Therefore, the structure is turned perpendicular to the drawing screen. This is called "project north". North orientation is only correct in the site plan. In other drawings, the north direction is changed so that the project can be drawn more easily and that the project can be understood by others. While this change is applied manually in Autocad; In Revit, the angle between project north and true north must be determined and processed as data to the program (See Fig.3.17).

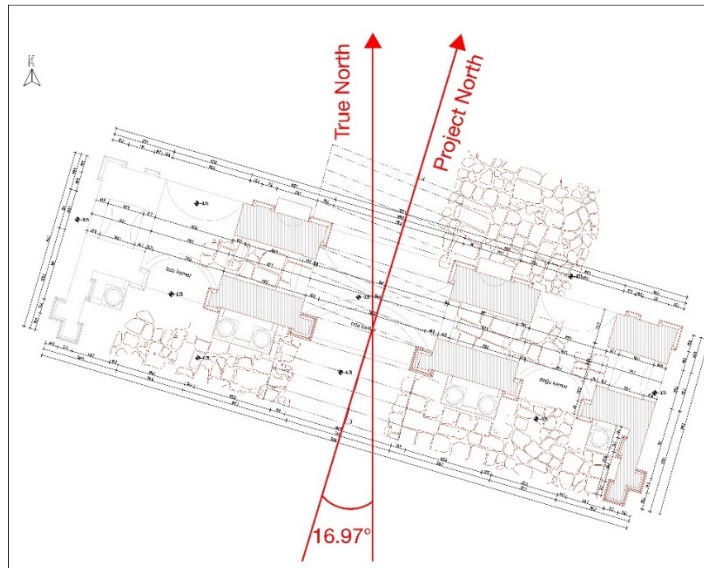


Figure 3. 17: True north settlement in the Revit. Source: Author's archive.

In Anavarza/Anazarbus Triumphal Arch restitution project, the angle between true north and project north must be measured, and the value must be entered in Revit. In this way, the project is automatically parallel to the true north direction in the site plan drawing, while in all other drawings, the project is perpendicular to the screen, in a word parallel to the project north axis. Before starting modeling in Revit, it is necessary to set Project north and true north.

The presence of an arrow indicating the true north direction makes it easy to make a correct setting in Revit, In the drawing that will be imported from Autocad in the site plan. The drawing to be imported into the site plan is the plan showing the project north, and after importing this drawing, the site plan drawing is opened by default in Revit. At this point, the orientation tab is set as project north by default in Revit. In this section, true north is selected from the orientation tab in the properties panel. In order to set the true north direction, the true north option must always be selected at the beginning (See Fig.3.18).

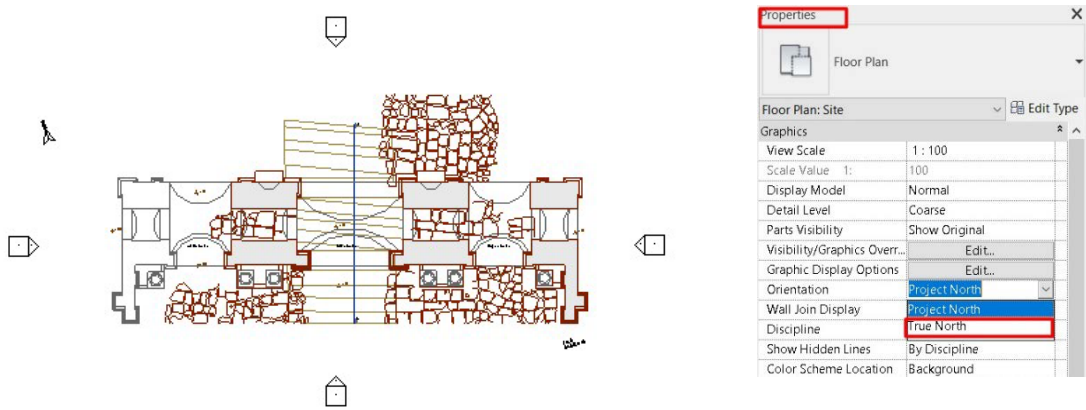


Figure 3. 18: Orientation tab in properties panel. Source: Author's archive.

After applying these adjustments, the angle value between true north and project north must be entered or manually rotated. This setting is executed under the manage tab in Revit. In the "Manage" tab, "Project location" section, "position" must be selected, and then the "Rotate true north" option is selected. The "rotate true north" command can be implemented in 2 ways. The first one is to enter the angle value in the "CCW Rotation angle" section. With this method, the angle value between project north and true north is entered in the specified blank area. However, since a universal system is accepted here when the angle value is written with a minus, a correct Site result is obtained. In this case, the angle between 16.97 is entered as -16.97 in the "CCW Rotation angle" section (See Fig.3.19).

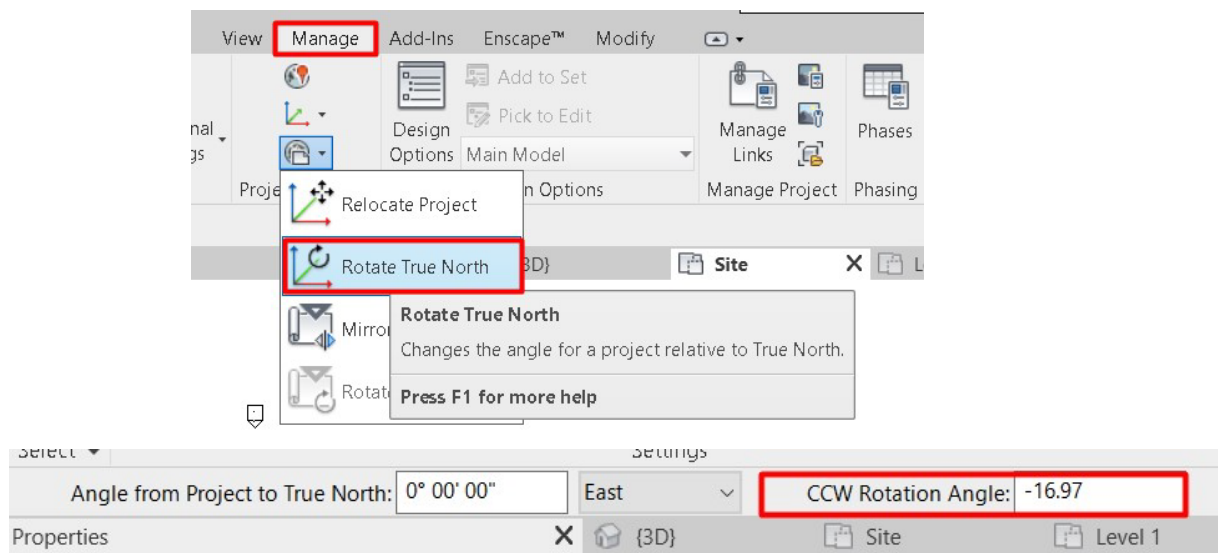


Figure 3. 19: CCW rotation angle method. Source: Revit user interface.

Another way is to manually make the non-vertical true north cursor page vertical on the drawing. The blue point that comes out with the "Rotate true north" command is

moved to the non-vertical north sign and rotated at the required angle. When the north sign is brought upright, it is rotated by 16.97 degrees. The same result will be obtained in both cases, and the project's true north and project north are set (See Fig.3.20).

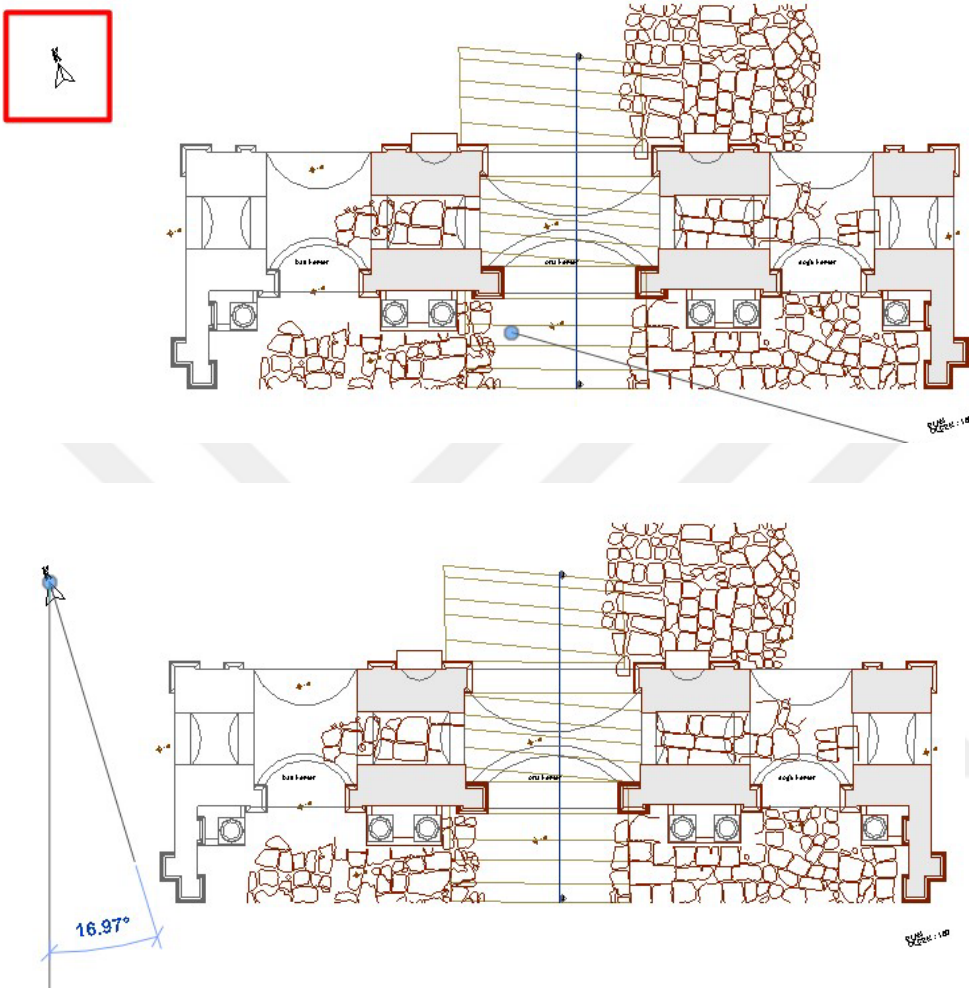


Figure 3. 20: Manually rotation angle method. Source: Author's archive.

Only the orientation part in Site Plan should appear as true north. In all other plans, the orientation part should appear as Project north. With this setting, the angle value between the building and the Y axis is added to Revit as data (See Fig.3.21).



Figure 3. 21: Plan view in true north and project north option. Source: Author's archive.

The fourth step of the "2D Project Data Entry into The Revit" section is the level settlement. After setting the project's true north and project north directions, the structure's elevation must be adjusted. The 0.00 level of the project is the determinative elevation, and the structure is built in Revit starting from this point. The 0.00 level in the 2D drawings in Autocad must be the same as the 0.00 level created in Revit. If the structure is started to be built based on the 0.00 elevation correctly, the remaining levels of the project will be correct. Level lines are not included in the 2D restitution project drawing of Anavarza/Anazarbus Triumphal Arch. Instead, the elevation data of the building element at each point of the project is indicated. Based on the location and properties of certain building elements, specific elevations were determined and recorded as levels in Revit. Levels continue with the names 1, level 2... by default, and this can be renamed if preferred.

Some of the levels placed on the building elements in Autocad are entered as the main level in Revit. At this point, the complex geometries of historical buildings and the fact that each facade is different from each other made difficult to determine the level.

For this reason, specific levels have been determined with the names of ground level, column starting level, column ending level, ceiling starting level and ceiling end level. In the 3D model built accurately based on these main levels, the elevation of each point can be measured and expressed in 2D (See Fig.3.22).

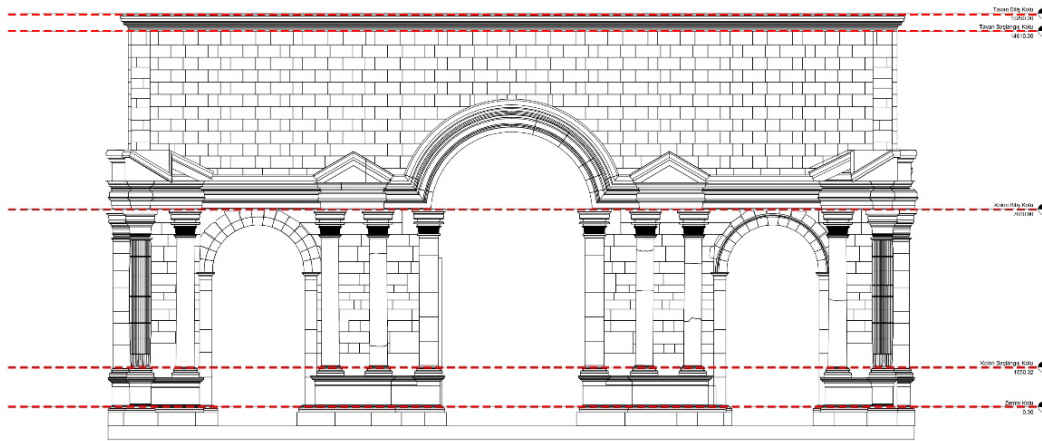


Figure 3. 22: Level settlement in Revit. Source: Author's archive.

The fifth step of the "2D Project Data Entry into The Revit" section is Importing 2D plan and facade drawings. After making the project's settings on Autocad in Revit, the next step is to transfer the 2D drawings to the Revit. In this section, 2D drawings are simplified by applying the Project reduction and eliminating useless lines steps in the previous section, "From 2D to Revit". First of all, north, south, east, west facade drawings and plan drawings are imported. These drawings form the base of the triumphal arch to be rebuilt in the Revit and guide it through the 3D modeling.

There are two ways to transfer the facade and plan 2D drawings to the Revit platform, and these are import CAD and link CAD commands. Import CAD and link CAD commands can be accessed from the "Insert" section. There is a very significant point that these commands differ from each other. In the Link CAD command, the Autocad drawing is not transferred to the project as a drawing; the file location is determined and linked to the project. Any changes made in the Autocad drawing are updated by reloading the Revit link file. In this way, there is no need to re-link the Autocad drawing every time, but in Revit this drawing is not perceived as lines, and no changes can be made on the drawing. In order to create a 3D masonry stone model using adaptive families, adaptive points must be placed at the intersection point of the lines of the drawing transferred from Autocad. Since the Autocad drawing linked to Revit is not transferred as a line, it is transferred as a link, so the lines do not have intersection

points. Adaptive points snap to the "nearest" parts of the lines, located close to the line that is not entirely correct. It has been determined that it would not be correct to transfer the Autocad drawing to Revit with this method to obtain an entirely correct HBIM as-built model. For this reason, the Link CAD method is not suitable for masonry stone model to be produced using adaptive family in historical buildings (See Fig.3.23).

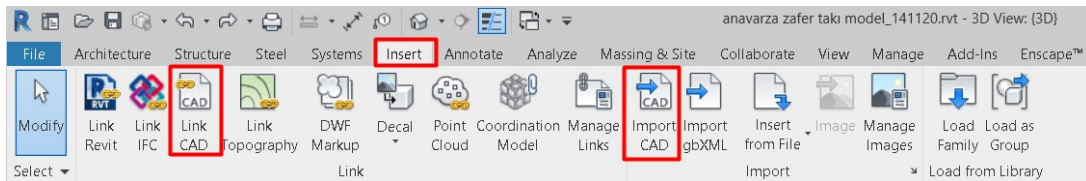


Figure 3. 23: Importing 2D plan and facade drawings. Source: Revit user interface.

Import CAD command is the second way to import the Autocad drawing into Revit. Before the Autocad drawing is transferred to Revit with the import CAD command, the level and position of the drawing to be imported is determined with the "Set Work Plane" command. If this process is not applied, the drawing will be imported into Level 1 plan view by default in Revit. There is no problem importing the plan drawing to the point in the default setting, but the same is not true for facade drawings. In order to import four different facades to the correct points, separate work planes should be set for each one. It can be set with the "set" command in the "work plane" section under the Architecture tab. The "Show" command can be used to see which plane the Current Work Plane (See Fig.3.24).

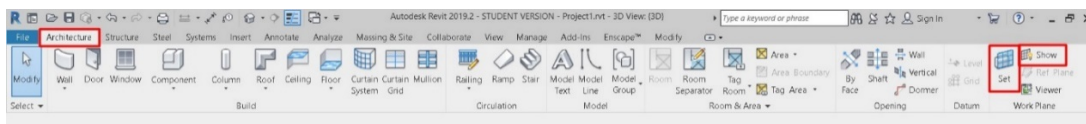


Figure 3. 24: Setting work plane. Source: Revit user interface.

Before importing 2D Autocad facade drawings, work plane adjustment is required in Revit. There are two ways to make this adjustment. The First of them, a surface parallel to the facade to be imported must be selected with the "pick plane" command. A second way is to apply the import command in the south view if the drawing of the south facade is imported. Thus, CAD drawings can be imported into Revit in the required shape and location (See Fig.3.25).

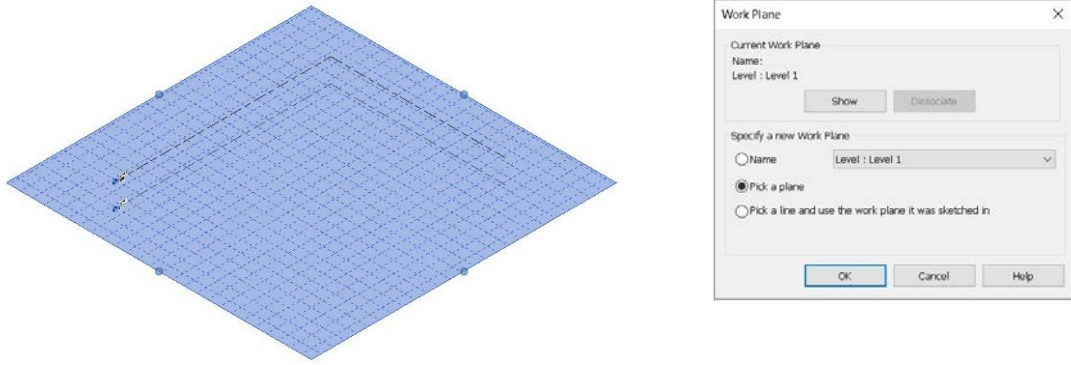


Figure 3. 25: Work plane adjustment. Source: Revit user interface.

All facade drawings and plan drawings are transferred to Revit sequentially with the import CAD command. At this point, it is necessary to import CAD format settings. The folder where the Autocad facade drawing is located, and then the facade drawing is selected. If the colors of the drawing to be imported are essential, "preserve" in the Colors section is selected; if not, "Black and White" is selected from the same section. The colors of the lines in the ATA restitution drawing are quite significant. Because the building elements and situations that the colors represent must be specified in Revit. For this reason, it is necessary to import 2D Autocad drawings in color. The layers to be visible can be selected from the Layers and Levels section. The drawing unit can be selected from the import unit section, and the position of the drawing can be selected from the positioning section. In the positioning section, there are four options: the center of the Autocad drawing automatically placed in the center of the Revit drawing, the origin of Autocad automatically placed in the origin of Revit or these two options set manually by the user. The "Place at" section is set to which level the drawing will be placed. Finally, the current view-only option is not checked. Because the current view only is selected, the drawing will only appear on the view to be imported. For example, the 2D facade drawing imported to the east facade is not visible in 3D view; it is only visible on the imported façade view. This means modeling using a single drawing base, and the relationship between the facades cannot be constructed in 3D view. For this reason, the Current view only tab should not be selected in order to create the HBIM as-built model (See Fig.3.26).

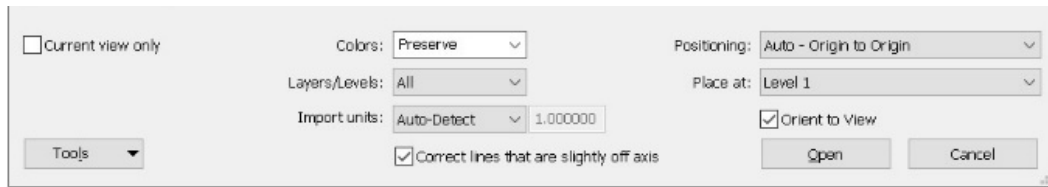


Figure 3. 26: Cad format settings. Source: Revit user interface.

After importing the facade drawings, the next step is to place the drawing in an accurate position. For this, it may be necessary to change the position of the drawing by moving the drawing after importing. Imported CAD drawing comes with "pin" by default. The term of pin means "prevent the change of element position" in Revit. It is not allowed to move the drawing without removing the pin, and the drawing can be moved to its correct position after the pin is removed (See Fig.3.27).



Figure 3. 27: Placing drawing to accurate position. Source: Author's archive.

The sixth step of the “2D Project Data Entry into The Revit” section is Bringing Together Plan and four facade drawings in the Revit. After the 2D plan drawing and facade drawings are imported to their correct positions, the next step is to bring these drawings together in Revit. At this stage, the designer must determine a specific reference point for all drawings, and the drawings in the 3D view are brought together according to these specified reference points. After the Autocad drawings of the ATA restitution project are imported into Revit, the drawings are tried to be placed in the right places in the 3D view. However, since each drawing block is produced separately in the Autocad, the building elements in the drawings do not match each other. Even though each facade drawing is consistent within the scope of that drawing, when all facades and plan drawings are brought together in Revit, minor mistakes are encountered. For this reason, the predetermined reference points of the drawings are accepted as accurate, and the drawings are brought together based on these points. Accordingly, in the combined drawings, incompatible lines are ignored. In the ATA, the reference point of the drawings has been determined as the ceiling starting level

and the ceiling ending level on the facades. Autocad drawings are brought together based on the ceiling starting level and the ceiling ending level (See Fig.3.28).

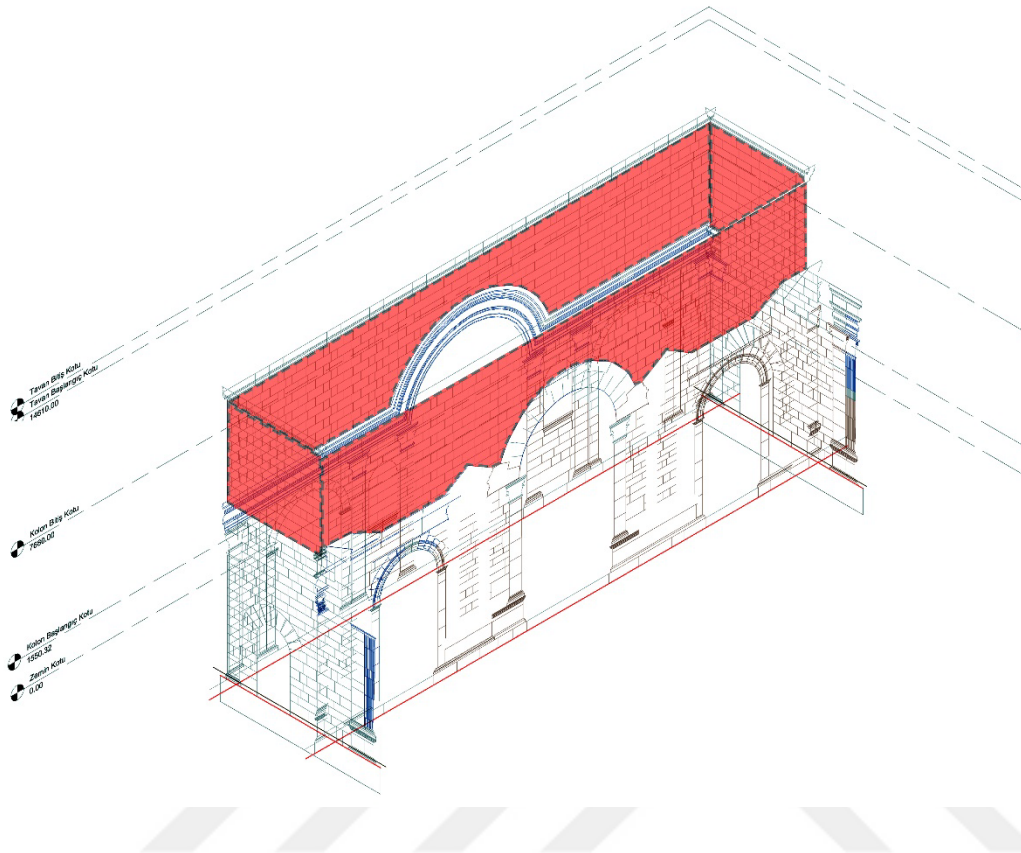


Figure 3. 28: Bringing together plan and 4 facade drawings in the Revit.
Source: Author's archive.

The seventh step of the "2D Project Data Entry into The Revit" section is 2D Drawing Exploding and Grouping. After importing 2D Facades to Revit, one last step is to be applied before starting 3D modeling. This last step is to explode the 2D drawings and then group the lines. This step is because the imported drawing must be exploded to place the adaptive points, which are explained in detail in the "Metric Generic Model Adaptive Family" section. If 2D drawings are not exploded after importing, and each element is not transformed into just a line, the placed points do not hold the intersections of the lines. If the points cannot be placed on the intersections of the lines, they are placed at another nearest point of the line each time, and they cannot make a correct location. For this reason, it is necessary to explode drawings and create a group from exploded lines in order to make the drawings controllable. The group name of the lines of each facade is named according to the facade to which it belongs. The drawing, which is transformed into lines after the drawing is exploded, takes place in the Revit with the layer names and properties it has in the same Autocad (See Fig.3.29).

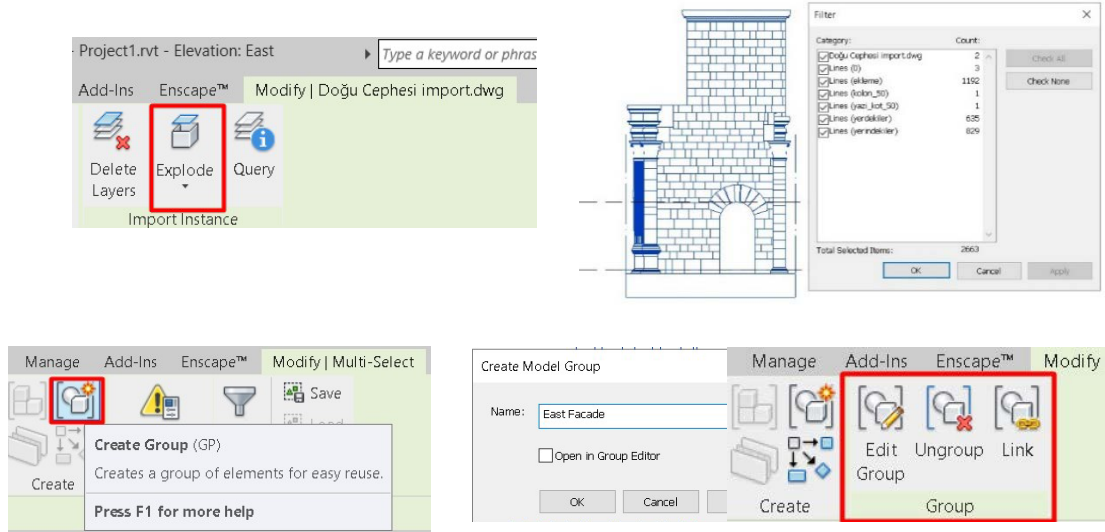


Figure 3. 29: 2D drawing exploding and grouping. Source: Revit user interface.

3.2.4 Geometric Data Entry to Revit

The following step after entering 2D project data into Revit to rebuild the Anavarza/Anazarbus Triumphal Arch restitution project in Revit is Creating a 3D model by referencing 2D drawings with developed adaptive components methodology. In the HBIM model of the ATA restitution project, the ways of masonry stone modeling in Revit are investigated within the scope of this thesis. However, due to the fact that each building element is integrated with each other, the others have been modeled quite simply with the generic model. The elements other than masonry stone are such as roof, columns, column heads, arches, triangular pediment and floors are modeled with the generic model. At this point, the decorations and reliefs in the drawing, especially on the column heads and arches, are not modeled within the scope of this thesis. The purpose of this thesis is to create masonry stone models with adaptive family, and other building elements are modeled only in terms of integrity. Ornaments and reliefs are not in the scope of this thesis.

It is decided to start HBIM as-built 3D modeling from the column ending level compatible with each other when the 2D drawings are brought together. It is necessary to start modeling from a section where the mistake is the least due to the continuity of the elements through the facades. For this reason, firstly, masonry stones of the north, east, south and west facades are modeled starting from the column ending level. Then, in order the intersection areas of the facades, which are the northeast, southeast,

southwest and northwest facades, are focused on throughout the modeling. In the last stage, the modeling of column, arch, roof, floor, triangular pediments is modeled with the generic model.

In order to rebuild the ATA restitution project with Creating 3D model by referencing 2D drawings with developed adaptive components methodology in Revit, the steps to be performed in Revit can be listed as follows:

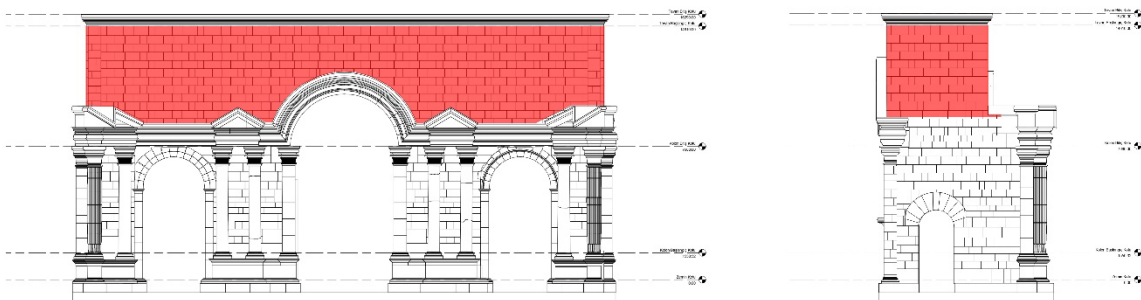
1. Modeling of Masonry Stones of North, East, South and West Facades in Sequence with creating adaptive family types

2. Modeling of Masonry Stones of North East, South East, South West, North West Facades in Sequence and intermediate part of the structure with creating adaptive family types

3. Modeling of Column, Arch, Roof, Floor, Triangular Pediments with Generic Model

The first step of the “Creating 3D Model by Referencing 2D Drawings with Developed Adaptive Components Methodology” section is Modeling of Masonry Stones of North, East, South and West Facades in Sequence with creating adaptive family types.

After importing the 2D Autocad drawings of all the facades into Revit and placing all the facades at an accurate position relative to each other, the next step is modeling masonry stones with an adaptive family. At this stage, the reasons for not starting modeling from the 0.00 level are both the complex and challenging geometries at the ground level of the project and the determination of the starting level of the ceiling as the exact matching point of the four facades. In this section, all masonry stones between the ceiling starting level and the column end level are produced with adaptive families (See Fig.3.30).



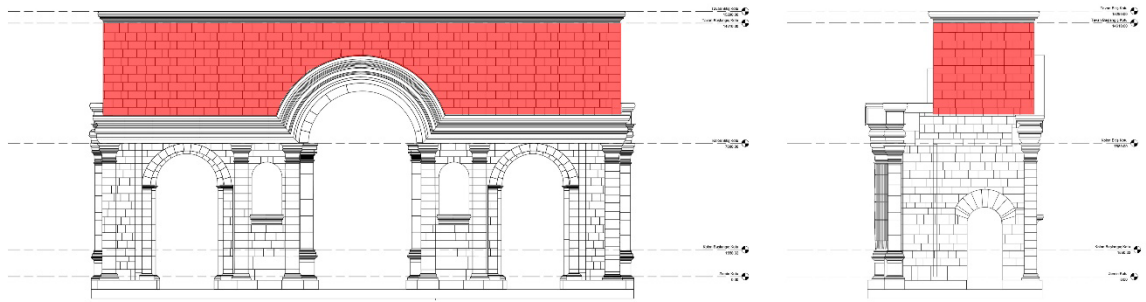


Figure 3. 30: Starting 3D modeling from matching point of the four facades.
Source: Author's archive.

The first step of modeling is to produce an adaptive family for the masonry stone walls on all facades after the ceiling starting level is accepted as the exact matching point for the four facades. The stages are explained in detail in the "Generic Model Adaptive Family" section. In this section, it is mentioned how to determine a 3D modeling way simply. As mentioned in the generic model adaptive family section, it is necessary to create the mass model and then settle the adaptive families by following the required steps on the 2D drawing. In this section, there are specific issues to consider when creating mass models. The first of these is to create a separate mass model with different names for each facade while creating mass models. In case all facades are created in a single mass model, file size exceeds, and edition becomes difficult. For this reason, it is approved to generate each facade in separate mass models and proceeded in this way. Another point that should be considered during modeling is that there are three different stages and three different colors representing those stages in the 2D drawings of the ATA restitution project. In the "2D Drawings' Data Analysis" section of the thesis, the current condition of the structural elements of the project is explained. In this section, the structural elements are divided into three sections: in situ blocks, inventory blocks, and undetectable blocks. In addition to producing a separate mass model for each facade, a separate mass model should be produced for sections with the same current condition categories. For example, if there is both an insitu block and an inventory block on the north facade, there must be two mass models on the north facade. If there are three of the insitu blocks, inventory blocks and undetectable blocks, three different mass models must be produced. The reason for this is the phasing command, which will be explained in detail in the "Categorization of the Elements and Phases" section of the thesis. In this section, some commands are applied to separate the project as in 2D drawings and to express it with different colors. Before

starting to model the ATA Restitution project, it should be taken into account that each facade should be produced as a separate mass model, and each building element with different current conditions should also be produced as a separate mass model. If these details are omitted at the beginning, a model that is difficult to work on in the future is formed.

First of all, a mass family is created with the commands "massing and site" and "in-place mass." Later, this family is named after the facade whose stones will be modeled with a 3D adaptive family. The points on which the adaptive family to be created will settle are placed on the drawing. 2D drawings are exploded and grouped in the "2D Drawing Exploding and Grouping" section. So, the points capture the endpoints of the lines while they are on the drawing and correctly place them at the intersections of the lines. The correct location of the point is understood from the fact that the points hold the endpoint of the lines while on the drawing. Endpoint text appears on the screen (See Fig.3.31).

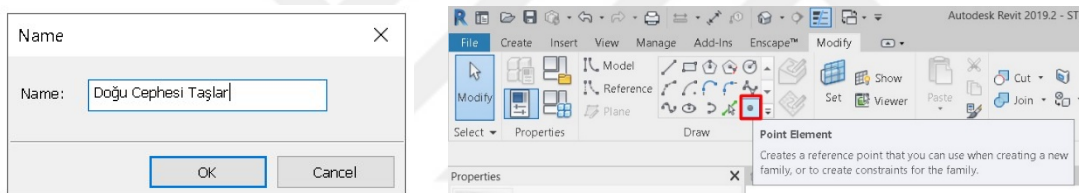


Figure 3. 31: Naming mass family. Source: Revit user interface.

In the facade drawing, points are placed in the section up to the column ending level, excluding the lines connecting with other facades. The corner points are left blank because a different adaptive family type will be produced and used when associated with the other facade. In this way, after covering the entire facade with points, the next step is to place the adaptive family type designed for the facades on the points (See Fig.3.32).

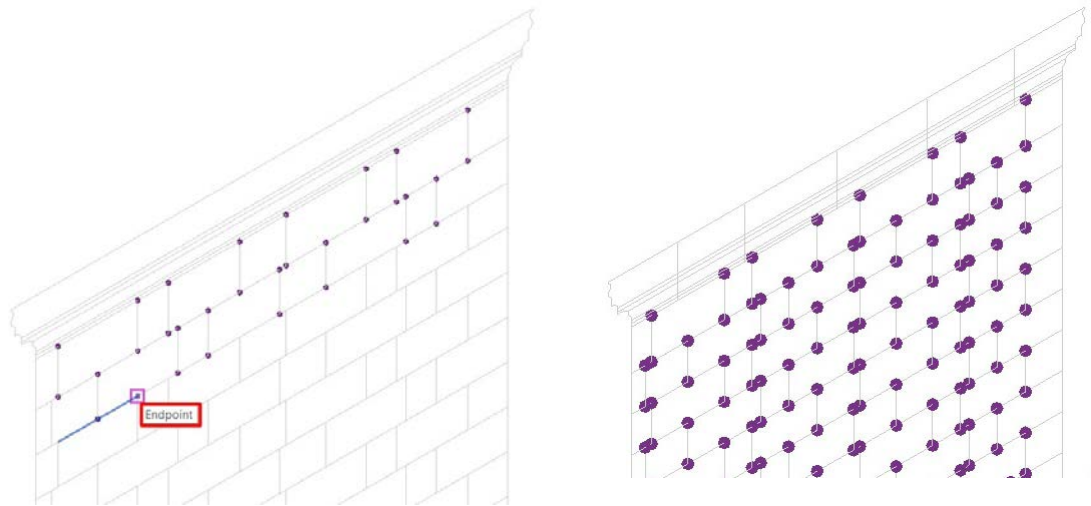


Figure 3. 32: Placing points in mass. Source: Author's archive.

In this section, the steps of applying the method determined in general on the ATA restitution project and the positive and negative effects encountered in this process will be explained. At this point, the design of each facade of the historical building is different from each other, and the adaptive family type required for each facade to be produced in 3D requires producing various adaptive family types. For this, all 2D facade drawings are analyzed at the beginning of the process, and all adaptive family types required for facades are produced during the modeling process. 3D HBIM model can be created in Revit of all ATA restitution project masonry stones with seven adaptive family types (See Fig.3.33). These adaptive family types are named according to their geometric form. Adaptive family types produced for the masonry stones of the ATA restitution project can be listed as follows.

- Masonry Stone_4 Points
- Masonry Stone_1 Curve_5 Points
- Masonry Stone_2 Curve_6 Points
- Masonry Stone_1 Curve_6 Points
- Masonry Stone_1 Circle_5 Points
- Masonry Stone_1 Circle_8 Points
- Masonry Stone_8 Points

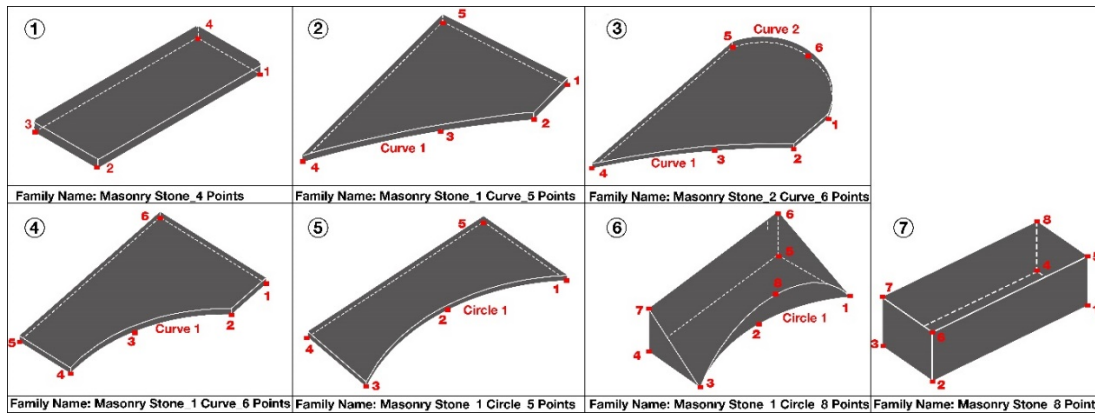


Figure 3.33: All adaptive family types created for HBIM model. Source: Author's Archive.

It is essential to name the family with a coding system to ensure standardization within the HBIM project. This coding system determines a rule framework for the family types in the project. In this way, the family names added to the project or changed later are followed in accordance with the code system. This system prevents mistakes and complexities in the modeling process. The coding of family names should be predicted in the later stages of the project. All initial coding should be executed in a planned manner so that the family names that will be produced in the future phase of the project do not conflict with the previous ones. This code can include the location of the family, geometry of the family or the family's physical properties. It is substantial that family naming is both understandable and not too long. It is set up so that the family name to be produced is different from each other. Otherwise, they are named "adaptive family 2", which is named as default in the project, creating uncertainty. The naming coding in the Anavarza/Anazarbus Triumphant Arch restitution project is based on the geometric form it has, as follows:

Adaptive Family Naming Code: Material_curve count_circle count_point count

Accordingly, it is planned to name the material, curve edge count, circle edge count and adaptive point count in the adaptive family type. For example, a brick material with six adaptive points and one curve edge is named "Brick_1 curve_6 points". Other features can be added to this naming, such as its facade. This depends entirely on the scope of the project and the level of detail of the model to be generated. In this way, in case a new family type is added to the project with a coding system, this coding rule is adhered to, and standardization in the naming system is ensured. In projects

produced with the BIM system, these project naming codes are determined at the beginning of the project and specified in the "BIM Execution Plan."

The first adaptive family type in the ATA restitution project is the family type with the most basic geometric form. This adaptive family type has four straight edges and four adaptive points (See Fig.3.34). For this, according to the code, the naming of an adaptive family type consisting of 4 adaptive points and made of stone is as follows:

Adaptive Family Naming Code: Material_curve count_circle count_point count

“Masonry Stone_4 Points”

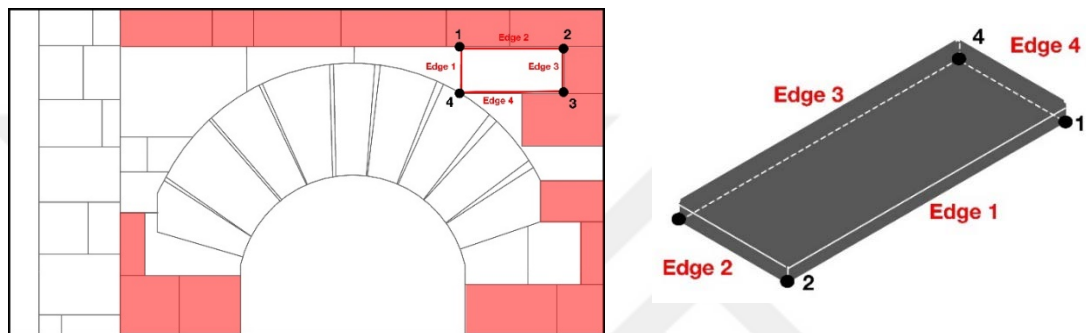


Figure 3. 34: “Masonry Stone_4 Points” adaptive family type. Source: Author's archive.

The seven adaptive family types produced in the Anavarza/Anazarbus Triumphal Arch restitution project will be explained in detail separately. However, after the adaptive family is created, the process will only be presented in the "Masonry Stone_4 Points" adaptive family type. This is because even if Adaptive family types change, the process in principle does not change.

After the steps determined on the 2D import Autocad project are implemented, the required the adaptive family is produced in the process. At this point, it is decided that how many adaptive points are produced the adaptive family has to consist of with the help of the section drawing in the restitution drawing. When the section drawing is examined, it is seen that the depth of the stone on all facades is 76.66 mm. Therefore, the masonry stones on the facades must be produced with the adaptive family, which has four adaptive points, and the depth of the object in the family must be 76.66 mm. The reason why the masonry stones on the facade are produced with four adaptive points is that the depth of the stone has the same in certain parts of the project. For this reason, an adaptive family has been produced with one surface stable or non-editable and the other side adaptable. In this way, masonry stones of all sizes in certain parts of

the facades are modeled with an adaptive family with four adaptive points. If it is to be examined in a more technical way, the masonry stones on the facade with a depth of 76.66 mm must be modeled with the adaptive family. The masonry stone created for this has x, y, z dimensions. While the x and y dimensions can be adapted to where they exist and can be edited within the project, the z measure is stable and not edited. The dimension z here is 76.66 mm and is constant (See Fig.3.35).

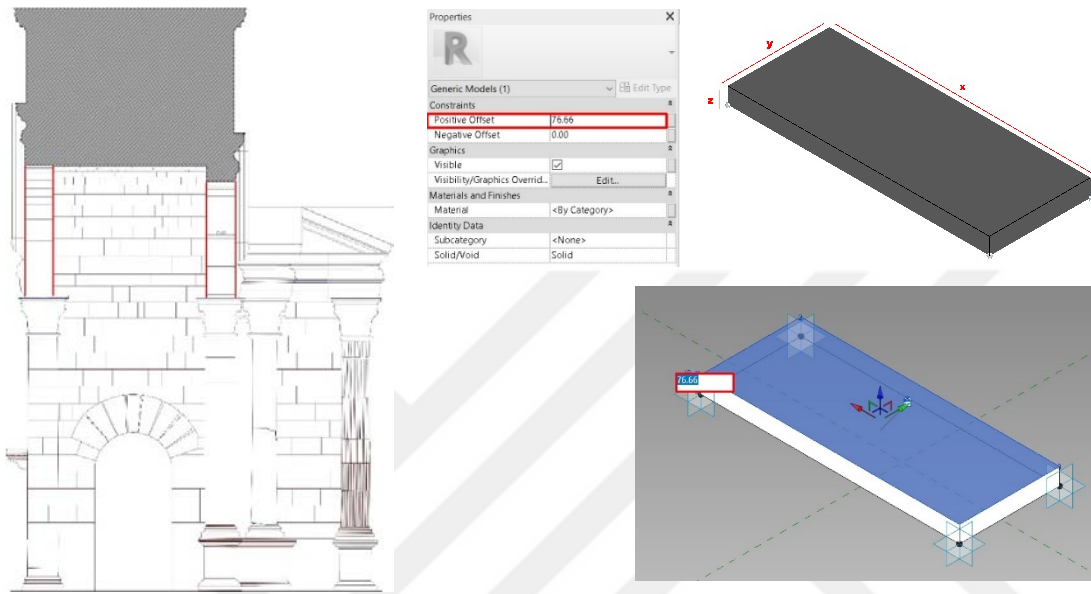


Figure 3. 35: Constant depth information of the stone. Source: Author's archive.

For the masonry stone sections of the facades with a constant depth, an adaptive family with 4 points is produced. Each family produced is named according to its geometric form. The names of these adaptive families are determined by the number of adaptive points they have.

The adaptive family naming, which contains 4 points, is determined as "masonry stone_4 points" within this project's scope. After the Masonry stone_4 points adaptive family type is generated, this family can be transferred to the ATA restitution project with the "load into project" command. The 3D modeling process, which started with the North facade, continues with the East, South and West facades after the adaptive families are produced.

Points are placed at all line intersections, except for lines that merge with other facades, on the modeled facade of the building. Then, the adaptive family type created before is selected with the "create" command and then the "component" command. The adaptive family type selection is made from the properties panel, and the name

determined while creating the adaptive family stage is searched. The name "Masonry stone_4 points" is placed on the points after choosing among the adaptive family type options. At this point, it is also taken into consideration that stones with only four straight edges and a depth of 76.66 mm can be produced with an adaptive family type named "masonry stone_4 points". It is necessary to produce different types of adaptive families while modeling parts of the ATA Restitution Project with different edge counts, shapes and geometries (See Fig.3.36).

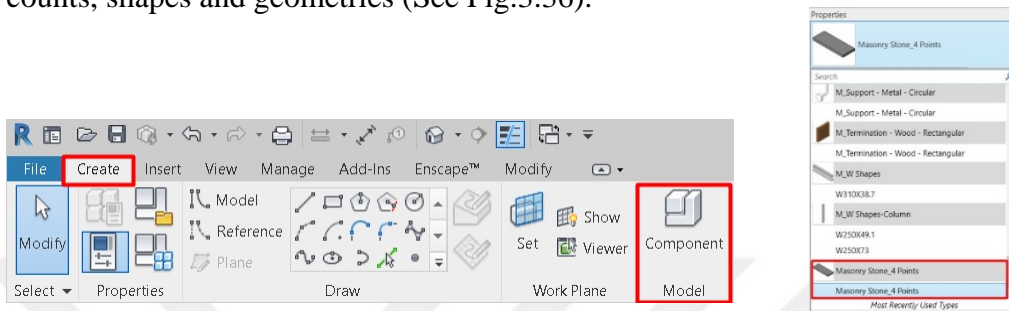


Figure 3. 36: Selecting adaptive family from properties panel. Source: Revit user interface.

In this section, the process of coming together of masonry stones to create the structure with adaptive family on the ATA restitution project will be explained within the scope of the thesis. The masonry stone_4 points adaptive family type loaded into the project and selected for modeling must be positioned by holding the points previously placed at the intersections of the lines. The masonry stone section of the building, which has four straight edges geometry with the adaptive family type named Masonry stone_4 points, is modeled by implemented the determining steps. Considering the numbers of each of the adaptive points, all stones are placed following the same numbers each time. To use this family type, the element to be modeled does not have 90 degrees, i.e., vertical edges. The substantial part here is that it has four straight edges, and the stone's depth is 76.66 mm. The "Masonry stone_4 points" family can be used in each section with these features (See Fig.3.37).

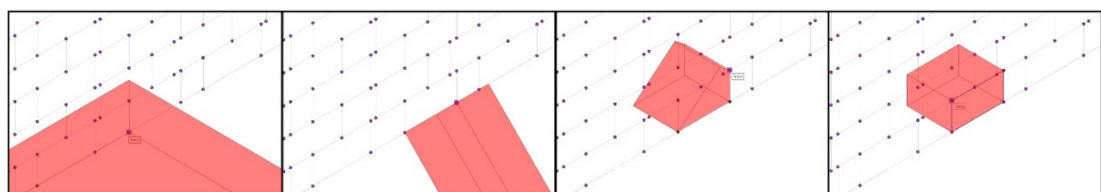


Figure 3. 37: Placing "Masonry Stone_4 points" into the model. Source: Author's archive.

"Masonry stone_4 points" adaptive family type catches the points while placing on the points and the text "point" appears on the drawing screen. When the correct point is caught, a pink circle is formed on the point, and thus it is understood that the point is kept and not another element. Adaptive families are placed consecutively adjacent to the model. At this point, the adaptive family placed second is positioned over the 2 points of the adaptive family placed first. Two adaptive families that are adjacent to each other share two points in the corner and one side. For this reason, when a common corner and edge of adaptive families is moved, the moving part of both adaptive family changes. This step is crucial in terms of creating total integrity on the as-built project and constructing the relationship between the building elements. In the process, after the adaptive families placed in the model in this way are transferred to the project, it may be necessary to make a change at some point in the adaptive family in some cases. In the process, after the adaptive families placed in the model in this way are transferred to the project, it may be necessary to make changes at some point in the adaptive family. This change is the case of editing the adaptive family in the project after transferring it to the project. There may be lines that do not connect with each other in the 2D drawing or parts that do not match each other when modeled in 3D. For this, a corner or an edge of the adaptive family can be moved during modeling within the project. The "driven by host" option, which was detailed previously, is used for such a change. After the Adaptive families are loaded into the project and placed on the points, it will not be a problem to keep the "driven by host" option selected if there is no need for editing within the project. If a change is required in the project, driven by host" option must be unchecked. In the ATA restitution project, the "driven by host" option is usually selected (See Fig.3.38).

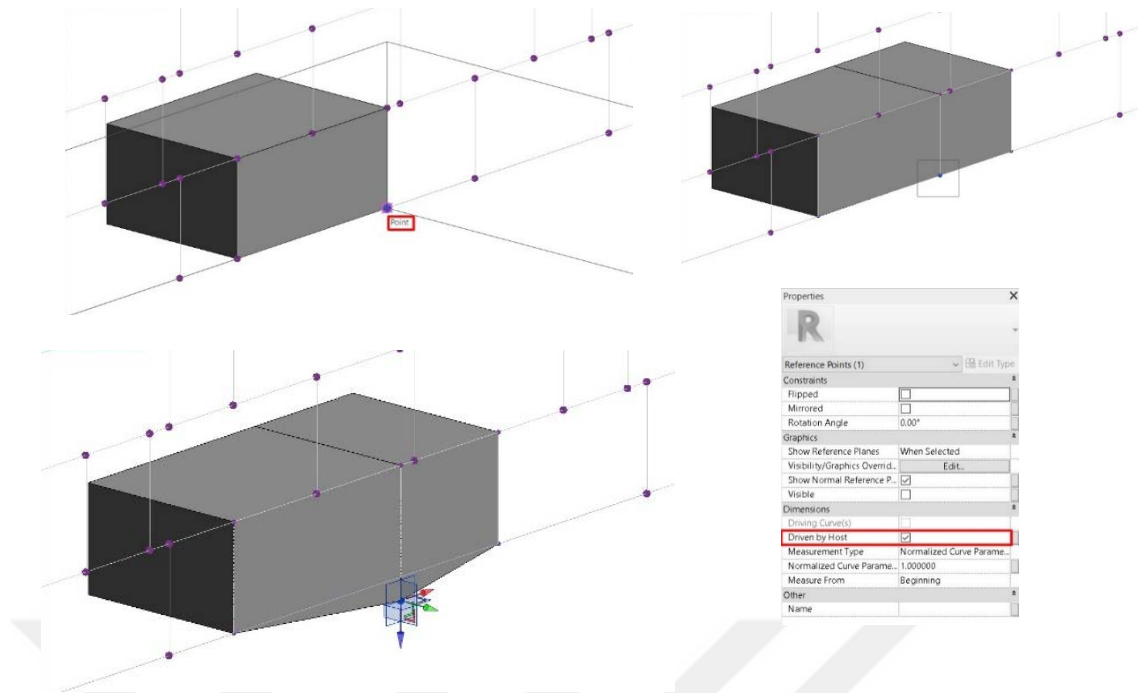


Figure 3. 38: Moving points with “driven by host” command. Source: Author's archive.

In the ATA restitution project, 3D modeling is started from Column Ending Level for convenience in the "Modeling of Masonry Stones of North, East, South and West Facades in Sequence with creating adaptive family types" section of the thesis. Then, all stone parts of the historic building with four straight edges are modeled in the same way. The adaptive family resettlement process steps, detailed for the northern facade, are also applied to the East, South and West facades. Since the same process is available on all facades, it is taken as an example only on the northern facade. As a result, "masonry stone_4 points", whose modeling is completed on the north, south, east and west facades, is the most common family type in the adaptive family type model.

Information such as adaptive family types, adaptive family counts, volumes and facades used in the project will be explained in detail in the "Documentation" section of the thesis. However, this section is illuminating to explain the distribution and counts of adaptive family types in the project in general. After the 3D HBIM Model was completed, according to the data obtained from the model, 615 pieces on the north side, 254 pieces on the west side and 554 pieces on the south side, 247 pieces of adaptive family type "masonry stone_4 points" are used on the east side. In addition, the "masonry stone_4 points" adaptive family type covers a volume of 61.81 m³ on

the East facade, 135.40 m³ on the North facade, 63.83 m³ on the West facade and 180.59 m³ on the South facade. According to these numbers, the total number of "masonry stone 4 points" adaptive family types used in the project is 1650 pieces. The total volume of the "masonry stone_4 points" adaptive family type covered in the project is 441.63 m³. "Masonry stone_4 points" adaptive family type, which has four adaptive points and four surface edges is the most common adaptive family type in the project (See Fig.3.39).

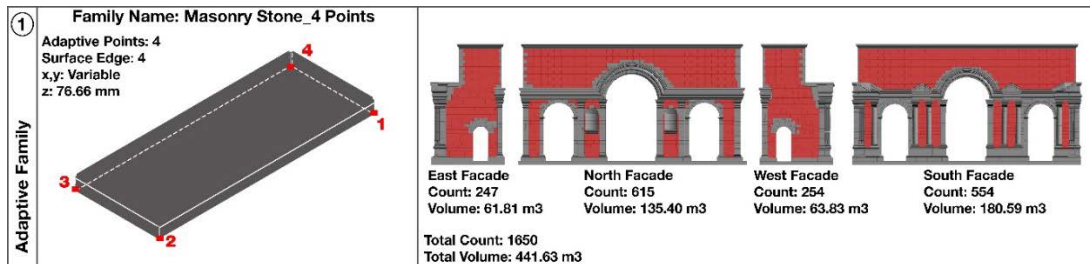


Figure 3. 39: Count, volumes, facades information of “Masonry Stone_4 Points” adaptive family type. Source: Author's archive

After modeling the north facade and other facades with four straight-sided masonry stone_4 points family is completed, new adaptive family types are produced for the four non-straight-sided stone parts of the project. Before starting modeling, the geometry of the 2nd Adaptive family type to be produced for the project and how many points will be placed on the facade drawing are analyzed. Although 4 points seem to be sufficient for the model of the stones adjacent to the stones that form the Arch part of the building, the curve of the stone edge forming the arch requires an edge of the adaptive family type to be produced. For this, 4 points are not enough to create the adaptive family type to be produced; it is created from 5 points. The Curve side of the stone is created by the combination of 3 points, not the combination of 2 points. When creating the adaptive family type, if the adaptive point is not placed on the curve edge of the geometry and the geometry is created from 4 points in total, some incompatibilities may occur in the project. If the curve edge value is constant and it is created from a total of 4 points, the curve edge cannot be edited in the project. At this point, the aim is to produce adaptive family types that must be adapted to every place it is placed. For this reason, adaptive points are added on the curve edge of the geometry to adapt to the points where the geometry will place.

This adaptive family type is named according to the coding system determined at the beginning of the project and according to its geometric form. Accordingly, the code

system created at the beginning of the modeling is followed, and the material, edge types and point numbers are considered. This adaptive family type has one curve edge and five adaptive points (See Fig.3.40). For this, according to the code, the naming of an adaptive family type consisting of 5 adaptive points, one curve edge and made of stone is as follows:

Adaptive Family Naming Code: Material_curve count_circle count_point count

Masonry stone_1 curve_5 points

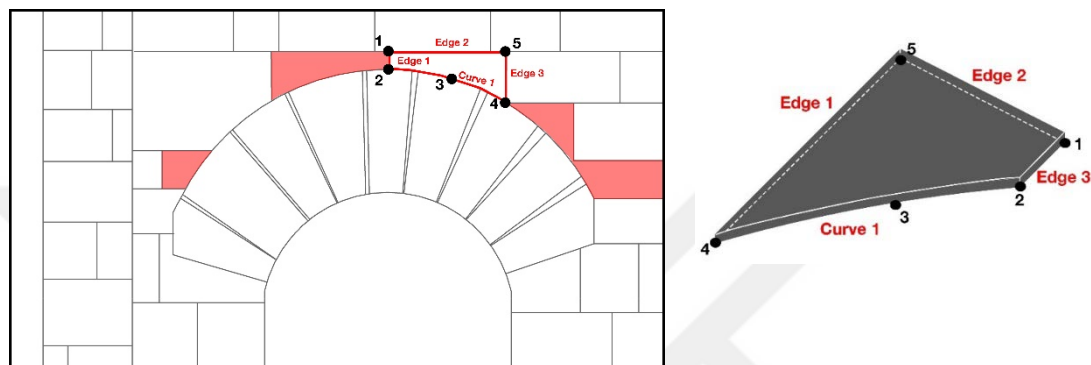


Figure 3. 40: “Masonry Stone_1 curve_5 points” adaptive family type.
Source: Author's archive.

While placing the adaptive family type with one curve edge and named as "Masonry stone_1 curve_5 points" on points in the project, the order and numbers where the points are placed are taken into consideration. When creating the adaptive family type, whichever number corresponds to the curve edge, the same number will also correspond to inside the project. In short, the order of point numbers is the same both when creating and placing them. For example, in the Adaptive family type created with the name Masonry Stone_1 curve_5 points, the curve edge points are determined with the numbers 2-3-4. In this case, the family is placed on the points in the model in a way that the numbers 2-3-4 coincide with the curve edge. If the curve edge is not placed in a different order of 2-3-4 figures, the desired geometric form cannot be obtained due to the curve edge.

The adaptive family type "Masonry Stone_1 curve_5 points" transferred to the project may appear big or small on the screen before being placed on the points initially. This is because when the adaptive family is being produced, it has different dimensions than in the project. However, since the feature of adaptive families is that they can adapt to the point where they are placed, different sizes do not create a problem. The adaptive

family type, initially transferred to the project with larger or smaller dimensions than its actual dimensions, reaches the required dimensions after it is placed in the points (See Fig.3.41).

The x and y dimensions of the adaptive family type named "Masonry Stone_1 curve_5 points" are variable in the "Masonry Stone_4 Points" family type. In case the adjacent adaptive points are moved, the x and y dimensions change throughout the movement. But here, as in the "Masonry Stone_4 Points" family type, the measure z is constant. According to the information obtained from the 2D section drawing, the depth measurement of the masonry stone, which is 76.66 mm, is entered as the z dimension information, and this value cannot be changed in the project.

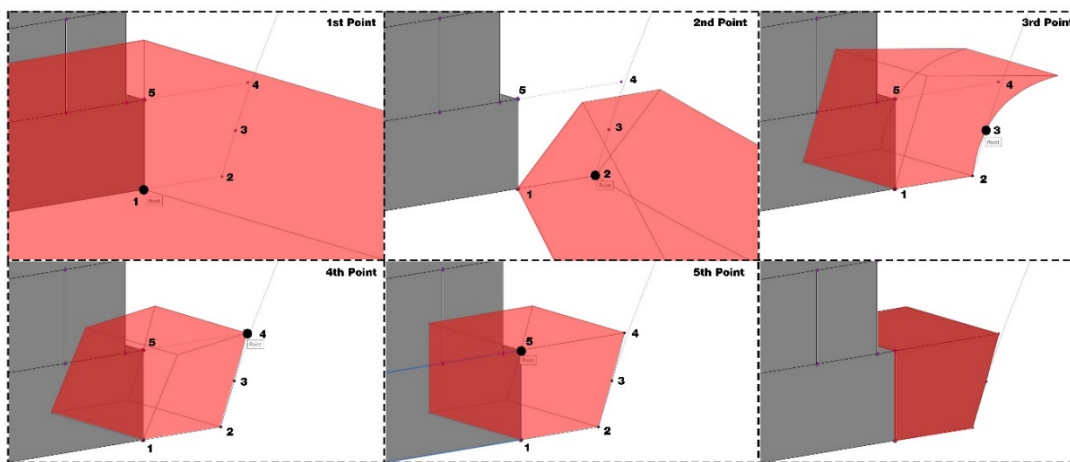


Figure 3. 41: Placing “Masonry Stone_1 curve_5 points” into the model.
Source: Author's archive.

Within the scope of this thesis, adaptive family types that can be edited after being transferred into the project are used to produce a 3D HBIM model based on 2D drawings. The purpose of this is to produce a single adaptive family type that can adapt to the position for each non-standard masonry stone. In this way, non-standard historical building elements are standardized with the determining tools. For this, a method is determined by using the tools in the Revit program. According to this method, changes can be applied after transferring the adaptive family type produced outside the project into the project by applying the established steps.

Adaptive families are transferred to the project with the steps followed in the method determined in the Revit program and placed on the points. Adaptive family types placed on the set of 3D points adopt the points they hold as their "host." The term "host" refers to the element in which the building elements are connected and move

together in Revit software. For example, the host of the Window family is the wall family. When the wall element is deleted from the project, the window element is also deleted because it loses its host, but if the window is deleted, the wall is not deleted. Wall family is in the system family category in the Revit program. For this reason, it has the feature of being a host. The points created in the project are also the host of the adaptive family that will be transferred to the project with the determined method. According to the host process, when the point is deleted, the adaptive family is also deleted; when the point is moved, the adaptive family moves with the point. In order for adaptive families to act with their hosts, the "driven by host" option, which is explained in detail in the "Metric generic model adaptive family" section, is unchecked. In this way, they become controllable and editable points. However, the "driven by host" option of each point placed is not removed during 3D modeling. Because the position of each point may not change, or it may not be edited. This option is used in parts where there are mistakes in 2D drawings or parts that do not match each other in the 3D model. In the ATA Restitution Project, it is determined that the lines do not converge with each other, especially in the arch drawings on the north and south facades, and this may cause a mistake in the model. In these parts, the points are moved to the required parts in order to create the 3D model in the most realistic way (See Fig.3.42).

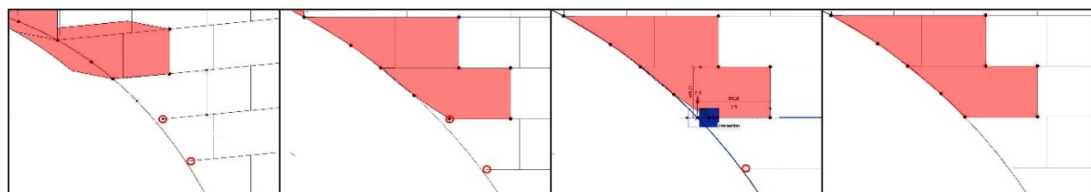


Figure 3. 42: Correcting mistakes on model with moving points. Source: Author's archive.

While the adaptive families are placed on the points in the project, the point order determined in the family is followed. However, there are situations where this order creates confusion on some facades. In such a case, after placing the adaptive family, the "flip" command is used. This can happen, especially if the points are located in a hard-to-reach place. After placing the adaptive family on the points, the flip command is mirrored only according to the plane where the points are located; there is no change in the point order. This may be a command that makes it easier for the designer in some cases. However, using flip command all the time is not an accurate modeling

method. The Flip command is located in the properties panel, and it can be changed from this panel (See Fig.3.43).

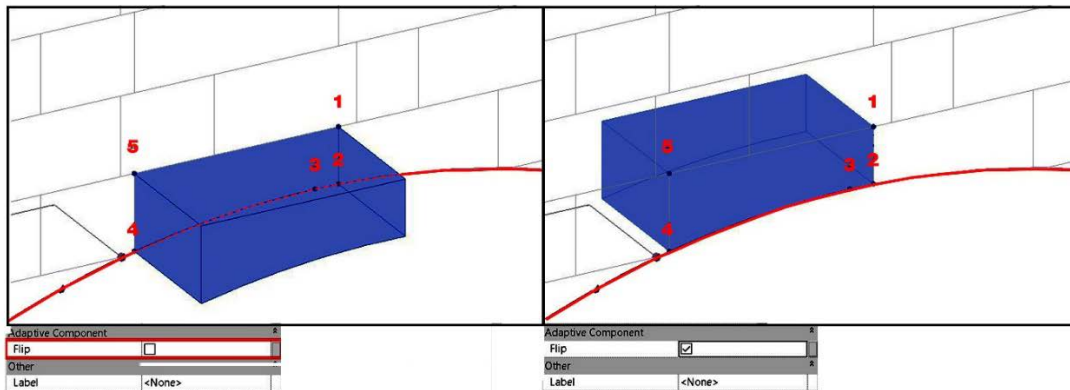


Figure 3. 43: Flipping adaptive family. Source: Author's archive.

After the 3D HBIM Model was completed, according to the data obtained from the model, 46 pieces on the north side, 11 pieces on the west side and 16 pieces on the south side, 9 pieces of adaptive family type “masonry stone_1 curve_5 points” are used on the east side. In addition, the “masonry stone_1 curve_5 points” adaptive family type covers a volume of 1.57 m³ on the East facade, 8.14 m³ on the North facade, 1.73 m³ on the West facade and 2.55 m³ on the South facade. According to these numbers, the total number of “masonry stone_1 curve_5 points” adaptive family types used in the project is 82 pieces. The total volume of “masonry stone_1 curve_5 points” adaptive family type covered in the project is 13.99 m³. “masonry stone_1 curve_5 points” adaptive family type, which has 5 adaptive points, 3 surface edges and 1 curve edge, is the 2nd most common family type in the adaptive family type in the project (See Fig.3.44).

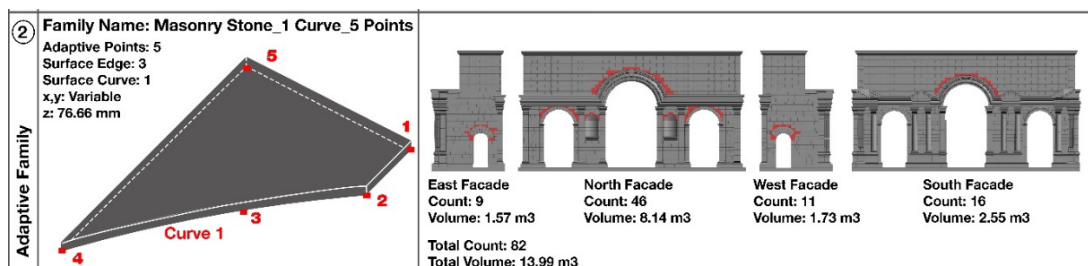


Figure 3. 44: Count, volumes, facades information of “Masonry Stone_1 curve_5 Points” adaptive family type. Source: Author's archive.

A new adaptive family type is generated to model the stones in the arch part of the historical structure building to complete the 3D HBIM model of the ATA restitution project. Before starting modeling, the geometry of the 3rd adaptive family type to be

produced for the project and how many points will be placed on the facade drawing are analyzed. This adaptive family type, which will form the stones in the arch part of the structure, is used mainly on the east and west facades. When the arch parts of the project are analyzed in the 2D drawings, it is obvious that the stones forming the arch have 2 curve edges and 2 straight edges. However, it should be noted that one of the curve edges is concave and the other is convex. Accordingly, 2 curve edges and 2 straight edges are required for modeling the adaptive family type to be produced for arch stones. For this, as mentioned before, the curve edge again consists of 3 adaptive points, and since the adaptive family type has a total of 2 curve edges, it consists of a total of 6 adaptive points. This adaptive family type is named according to the coding system determined at the beginning of the project and according to its geometric form. Accordingly, the code system created at the beginning of the modeling is followed, and the material, edge types and point numbers are considered. This adaptive family type has 2 curve edge and 6 adaptive points (See Fig.3.45). For this, according to the code, the naming of an adaptive family type consisting of 6 adaptive points, 2 curve edges and made of stone is as follows:

Adaptive Family Naming Code: Material_curve count_circle count_point count

Masonry Stone_2 Curve_6 Points

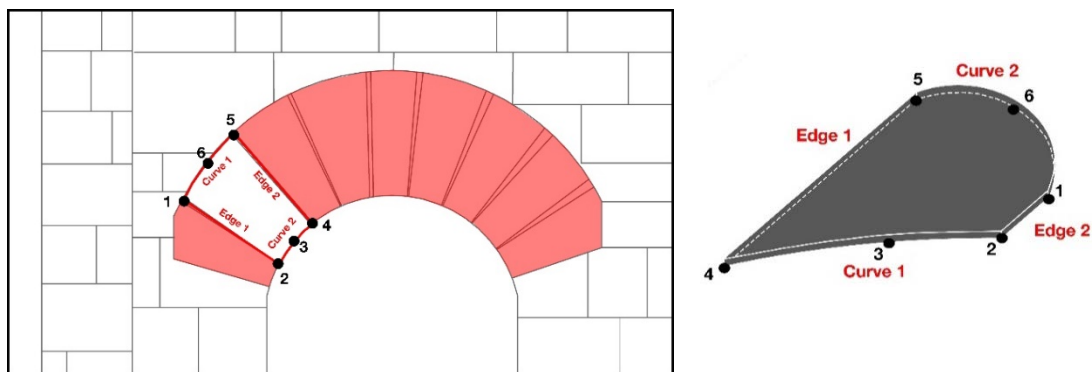


Figure 3. 45: “Masonry Stone_2 curve_6 points” adaptive family type.
Source: Author's archive.

The adaptive family type, which is produced for the arch parts of the ATA restitution project and named "Masonry Stone_2 Curve_6 Points", has a difference from other adaptive family types. "Masonry Stone_2 Curve_6 Points" adaptive family type has 2 curve edges, and one of these edges is concave, and the other is convex. After the adaptive family is transferred to the project, the numbers of the points forming the

concave curve edge in the adaptive family should be the same as the number of the concave numbers in the project. The edge determined as concave in the Adaptive family is in its own part in the project; The edge determined as convex in the adaptive family is placed in its own part by following the point order. Apart from this difference, it also has common points with other adaptive family types. As in other family types, "Masonry Stone_2 Curve_6 Points" adaptive family type's x and y dimensions are variable. They adapt to where it is placed, and when the host point is moved, this adaptive family type moves simultaneously. In addition, the z dimension value is constant as in other adaptive family types. According to the information obtained from the 2D cross-section drawing, the depth of the masonry stone, which is 76.66 mm, is entered, and this value cannot be changed in the project.

After the 3D HBIM Model was completed, according to the data obtained from the model, 30 pieces on the north side, 7 pieces on the west side and 30 pieces on the south side, 8 pieces of adaptive family type “Masonry Stone_2 Curve_6 Points” are used on the east side. In addition, the “Masonry Stone_2 Curve_6 Points” adaptive family type covers a volume of 2.42 m³ on the East facade, 4.75 m³ on the North facade, 2.32 m³ on the West facade and 3.01 m³ on the South facade. According to these numbers, the total number of “Masonry Stone_2 Curve_6 Points” adaptive family types used in the project is 75 pieces. The total volume of the “Masonry Stone_2 Curve_6 Points” adaptive family type covered in the project is 12.5 m³. “Masonry Stone_2 Curve_6 Points” adaptive family type, which has 6 adaptive points, 2 surface edges and 2 curve edges, is the 3rd most common family type in the adaptive family type in the project (See Fig.3.46).

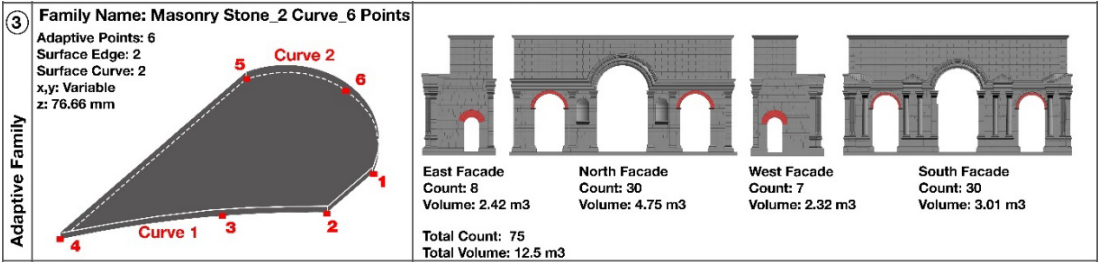


Figure 3. 46: Count, volumes, facades information of “Masonry Stone_2 curve_6 Points” adaptive family type. Source: Author's archive.

Another adaptive family type to be produced for the completion of the HBIM model of the ATA restitution project is the 4th Adaptive family type. This adaptive family type is generally located around the stones forming the arch, such as the "masonry

stone_1 curve_5 points" family type. Also, it generally resembles the family type "masonry stone_1 curve_5 points" geometrically. The only difference is that this adaptive family type to be generated has an extra edge. Before starting modeling, the geometry of the 4th adaptive family type to be produced for the project and how many points will be placed on the facade drawing are analyzed. This adaptive family type, which is applied at several points in the 3D model, is one of the least used family types in the project. It is located only on the north and west sides of the project. When the geometric form of the adaptive family type is examined, it is observed that it has 4 straight edges and 1 curve edge. Since the adaptive family has 1 curve edge, 3 adaptive points are used, and for the adaptive family, in this case, a total of 6 adaptive points are used. This adaptive family type, located next to the arch stones in the project, is named according to its geometric form. Accordingly, the code system created at the beginning of the modeling is followed and the material, edge types and point numbers are considered. This adaptive family type has 1 curve edge and 6 adaptive points (See Fig.3.47). For this, according to the code the naming of an adaptive family type consisting of 6 adaptive points, 2 curve edges and made of stone is as follows:

Adaptive Family Naming Code: Material_curve count_circle count_point count

Masonry Stone_1 Curve_6 Points

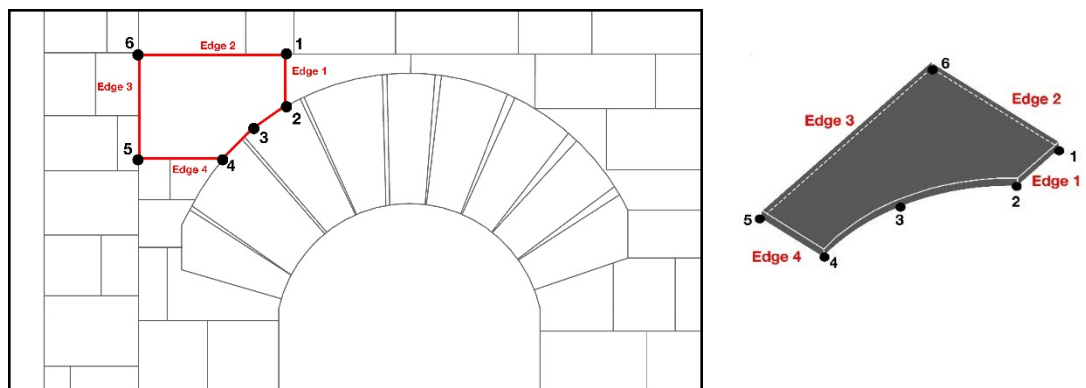


Figure 3. 47: "Masonry Stone_1 curve_6 points" adaptive family type.
Source: Author's archive.

The stones adjacent to the stones forming the arches of the ATA restitution project are produced with the adaptive family type named "Masonry Stone_1 Curve_6 Points". "Masonry Stone_1 Curve_6 Points" adaptive family type is the least used family type in the project. The reason for this situation is that there is mostly an adaptive family type named "masonry stone_1 curve_5 points" around the stones forming the arch.

Since the edge count of this family type is not sufficient in some cases, the "Masonry Stone_1 Curve_6 Points" adaptive family type is produced. In fact, when the family types "masonry stone_4 points" and "masonry stone_1 curve_5 points" are combined with geometric, the family type "Masonry Stone_1 Curve_6 Points" is comprised. However, if the combination of 2 adaptive family type method is applied instead of producing a new family, stone count seemed higher appear in the schedule table to be extracted at the end of the project. In both methods, the stones' volume is the same. Therefore, the volume calculation is accurate in the created schedule table, but the count of stones is excessive. For this reason, a new adaptive family type named "Masonry Stone_1 Curve_6 Points" is produced even if it will be used less in the project (See Fig.3.48).

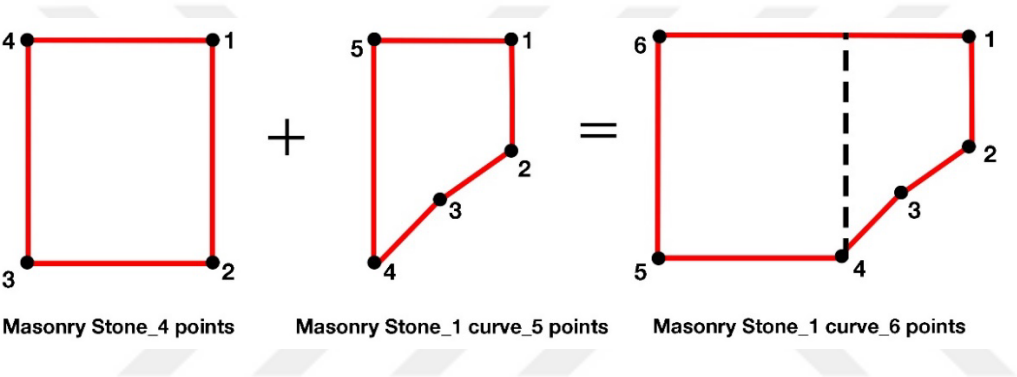


Figure 3. 48: Combination of “Masonry Stone_4 Points” and “Masonry Stone_1 curve_5 points”. Source: Author's archive.

As in other family types, “Masonry Stone_1 Curve_6 Points” adaptive family type’s x and y dimensions are variable. They adapt to where it is placed, and when the host point is moved, this adaptive family type moves simultaneously. In addition, the z dimension value is constant as in other adaptive family types. According to the information obtained from the 2D cross-section drawing, the depth of the masonry stone, which is 76.66 mm, is entered, and this value cannot be changed in the project.

After the 3D HBIM Model was completed, according to the data obtained from the model, 2 pieces on the north side, 1 piece on the west side and 0 pieces on the south side, 0 pieces of adaptive family type “Masonry Stone_1 Curve_6 Points” are used on the east side. In addition, the “Masonry Stone_1 Curve_6 Points” adaptive family type covers a volume of 0 m3 on the East facade, 0.42 m3 on the North facade, 0.73 m3 on the West facade and 0 m3 on the South facade. According to these numbers, the total number of “Masonry Stone_1 Curve_6 Points” adaptive family types used in the project is 3 pieces. The total volume of “Masonry Stone_1 Curve_6 Points” adaptive

family type covered in the project is 1.15 m³. The “Masonry Stone_1 Curve_6 Points” adaptive family type, which has 6 adaptive points, 4 surface edges and 1 curve edge, is the 5th most common family type in the adaptive family type in the project (See Fig.3.49).

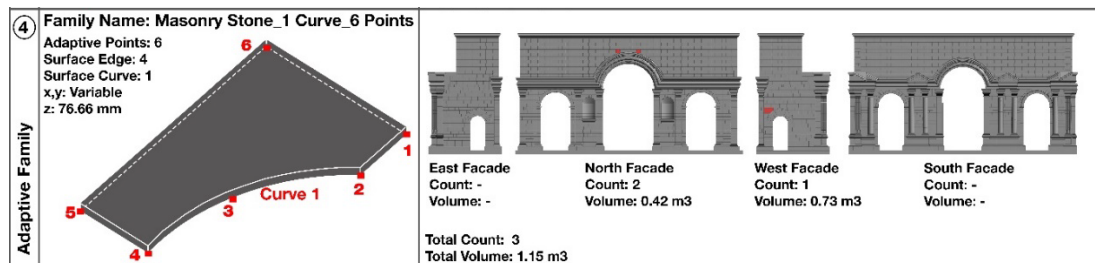


Figure 3. 49: Count, volumes, facades information of “Masonry Stone_1 curve_6 Points” adaptive family type. Source: Author's archive.

Another adaptive family type to be produced to complete the HBIM model of the ATA restitution project is the 5th Adaptive family type. This adaptive family type is located within semicircular niches on the north facade only. This adaptive family type forms the semicircular niches located only on the north facade of the project. Geometrically, it has a different form than other adaptive family types. Another point that differs from other adaptive family types is the z constant value. In this adaptive family, the z value is 45.20 mm, not 76.66mm, as in other adaptive family types. Until this part, points are usually placed on the 2D facade drawing, and adaptive families are placed on points. However, in this adaptive family type, the points are placed on the plane of the plan, and the height on the facade remains constant. The reason for such a difference is the created geometric form. The adaptive family type is placed on the points in the plane of the plan so that the geometry of the semicircular niche section visible on the facade is in a concave form, and the backside is in a rectangular form. Before starting modeling, the geometry of the 5th adaptive family type to be produced for the project and how many points will be placed on the facade drawing are analyzed. The adaptive family type has 3 straight edges and 1 circle edge. As in the curve edge, 3 adaptive points must be used for the circle edge. The adaptive family type, which will form the stones in the semicircular niche section on the north facade of the project, is named according to its geometric form. Accordingly, the code system created at the beginning of the modeling is followed, and the material, edge types and point numbers are considered. This adaptive family type has 1 circle edge and 5 adaptive points (See

Fig.3.50). For this, according to the code, the naming of an adaptive family type consisting of 5 adaptive points, 1 circle edge and made of stone is as follows:

Adaptive Family Naming Code: Material_curve count_circle count_point count

Masonry Stone_1 Circle_5 Points

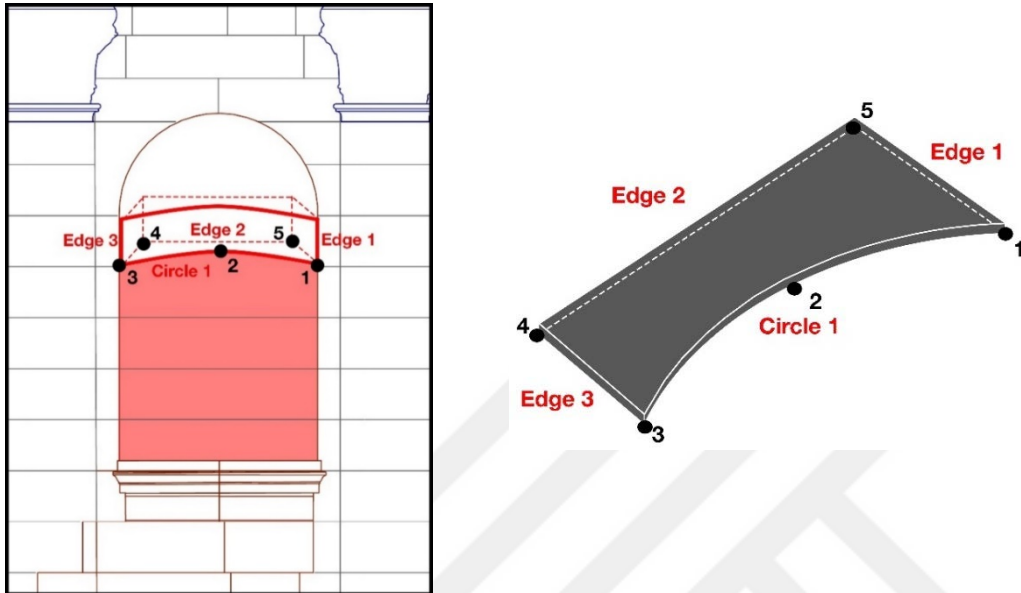


Figure 3. 50: “Masonry Stone_1 circle_5 points” adaptive family type.
Source: Author's archive.

An adaptive family type named “Masonry Stone_1 Circle_5 Points” is produced for the semicircular niches on the north facade of the ATA restitution project. After the 3D HBIM Model was completed, according to the data obtained from the model, 10 pieces on the north side, 0 pieces on the west side and 0 pieces on the south side, 0 pieces of adaptive family type “Masonry Stone_1 Circle_5 Points” are used on the east side. In addition, the “Masonry Stone_1 Circle_5 Points” adaptive family type covers a volume of 0 m³ on the East facade, 2.51 m³ on the North facade, 0 m³ on the West façade and 0 m³ on the South facade. According to these numbers, the total number of “Masonry Stone_1 Circle_5 Points” adaptive family types used in the project is 10 pieces. The total volume of the “Masonry Stone_1 Circle_5 Points” adaptive family type covered in the project is 2.51 m³. “Masonry Stone_1 Circle_5 Points” adaptive family type, which has 5 adaptive points, 3 surface edges and 1 circle edge, is the 4th most common family type in the adaptive family type in the project (See Fig.3.51).

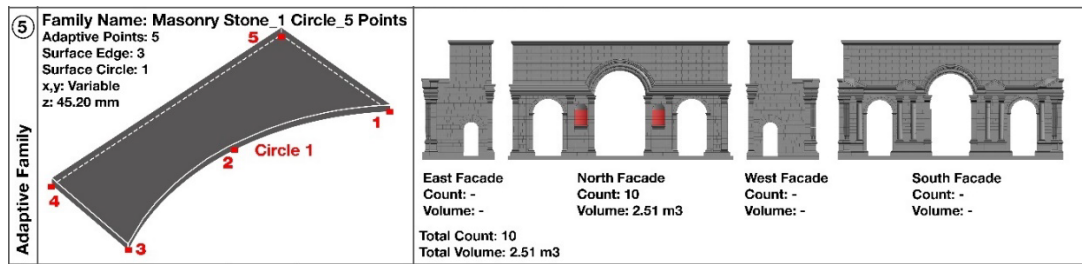


Figure 3. 51: Count, volumes, facades information of “Masonry Stone_1 circle_5 Points” adaptive family type. Source: Author's archive.

Another adaptive family type to be produced to complete the HBIM model of the ATA restitution project is the 6th Adaptive family type. This adaptive family type is located in the whole building only on the north facade, just like the "Masonry Stone_1 Circle_5 Points" adaptive family type. This adaptive family type to be produced is one piece stone on the semicircular niche stones where the "Masonry Stone_1 Circle_5 Points" adaptive family type is located. It is quite different from other adaptive family types in terms of geometric form and generation process. The x, y and z values of this family type are all variable, and also these values can be adapted according to the location. Until this part of the project, adaptive family types are generally placed on points on the facade surface, and adaptive family types are placed on these points. However, a three-dimensional point cluster is placed for the end stone of the semicircular niche section located only on the north facade. After determining the form of the point cluster placed on the facade, it is necessary to produce an adaptive family suitable for this point cluster. At this point, it is seen that the steps determined so far are not sufficient for the adaptive family type, which has a different geometric form from the others. For this, experiments are performed within the adaptive family to create a more flexible geometric form. The process generally followed for the production of adaptive family types with non-standard masonry stones in historical buildings is generally similar. This process is to place adaptive points on the facade and determine a fixed or variable value in the z plane. However, this family type does not have a 3-dimensional symmetrical geometric form, and each part of this form consists of asymmetric geometries, unlike the others. For this reason, the required geometric form could not be obtained when the modeling process applied in other adaptive family types was applied in this family type. For this purpose, reference lines of the adaptive family type on different surfaces are created separately, and a geometric form is produced in the section plane, not in the planned plane. Due to the created adaptive family type, it

is experienced how the stones will be formed with the 3-Dimensional adaptive point cluster, which has different geometric forms and an unsymmetrical geometry (See Fig.3.52).

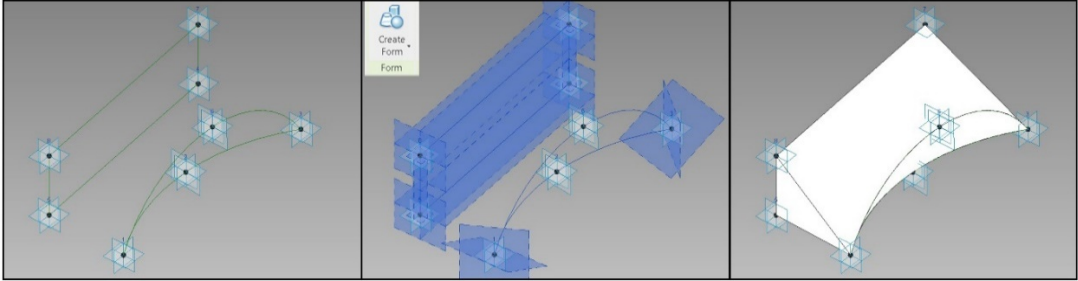


Figure 3. 52: Generating unsymmetrical geometry. Source: Author's archive.

The adaptive family type has 8 adaptive points, 3 straight edges and 1 circle edge. As in the curve edge, 3 adaptive points must be used for the circle edge. The adaptive family type, which will form the ending stone in the semicircular niche section on the north facade of the project, is named according to its geometric form. Accordingly, the code system created at the beginning of the modeling is followed, and the material, edge types and point numbers are considered. This adaptive family type has 1 circle edge and 8 adaptive points (See Fig.3.53). For this, according to the code the naming of an adaptive family type consisting of 8 adaptive points, 1 circle edge and made of stone is as follows:

Adaptive Family Naming Code: Material_curve count_circle count_point count

Masonry Stone_1 Circle_8 Points

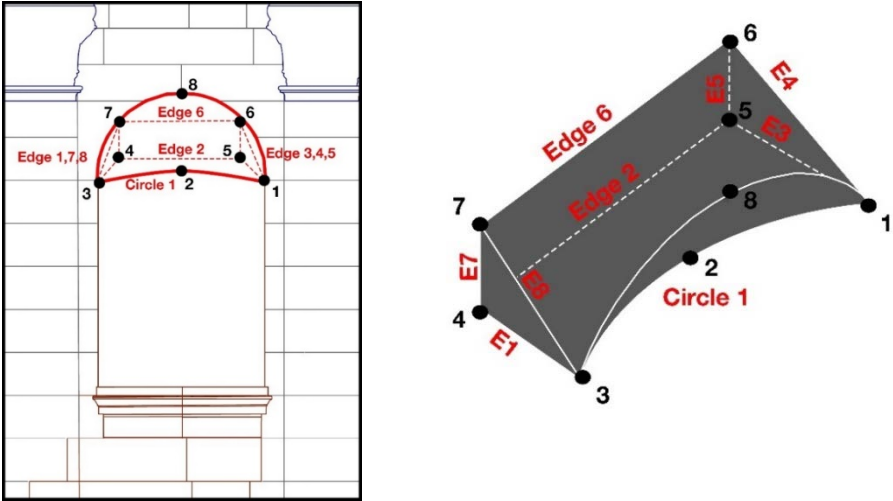


Figure 3. 53: “Masonry Stone_1 Circle_8 Points” adaptive family type. Source: Author's archive.

An adaptive family named "Masonry Stone_1 Circle_8 Points" is produced for the ending stone of the semicircular niches on the north facade of the ATA restitution project. After the 3D HBIM Model was completed, according to the data obtained from the model, 2 pieces on the north side, 0 pieces on the west side and 0 pieces on the south side, 0 pieces of adaptive family type "Masonry Stone_1 Circle_8 Points" are used on the east side. In addition, the "Masonry Stone_1 Circle_8 Points" adaptive family type covers a volume of 0 m³ on the East facade, 0.83 m³ on the North facade, 0 m³ on the West facade and 0 m³ on the South facade. According to these numbers, the total number of "Masonry Stone_1 Circle_8 Points" adaptive family types used in the project is 2 pieces. The total volume of the "Masonry Stone_1 Circle_8 Points" adaptive family type covered in the project is 0.83 m³. "Masonry Stone_1 Circle_8 Points" adaptive family type, which has 8 adaptive points, 3 surface edges and 1 circle edge, is the least common family type in an adaptive family type project (See Fig.3.54).

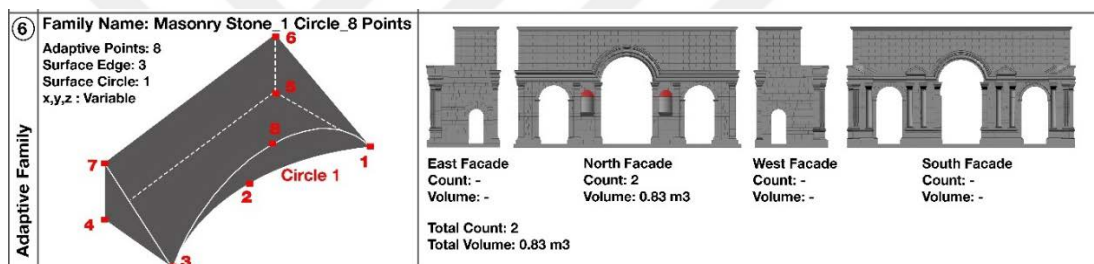


Figure 3. 54: Count, volumes, facades information of “Masonry Stone_1 circle_8 Points” adaptive family type. Source: Author's archive.

6 adaptive family types described in detail in this section are used for the modeling of non-standard masonry stones of the ATA restitution project. These 6 adaptive family types with various geometric forms and features are conveyed in detail by supporting them with visuals. Data such as the names, number of adaptive points, geometric forms, facades where it is located, how many stones are used on which facade, the covered volume of these adaptive family types produced to create a 3D model of the historical building are compiled. Adaptive family types, which are generally similar to each other, differ from each other in geometric form. It is similar throughout the production process of the adaptive family type. But as the geometric form became more complex, the methods of its production changed. The information of the number and volume of adaptive family types will be explained in detail in the section titled "Documentation". However, adaptive family types are shown in tables in this section in order to categorize. The masonry stones on all facades are modeled with 6 adaptive

family types in order to produce the HBIM model of the ATA Restitution project (See Fig.3.55).

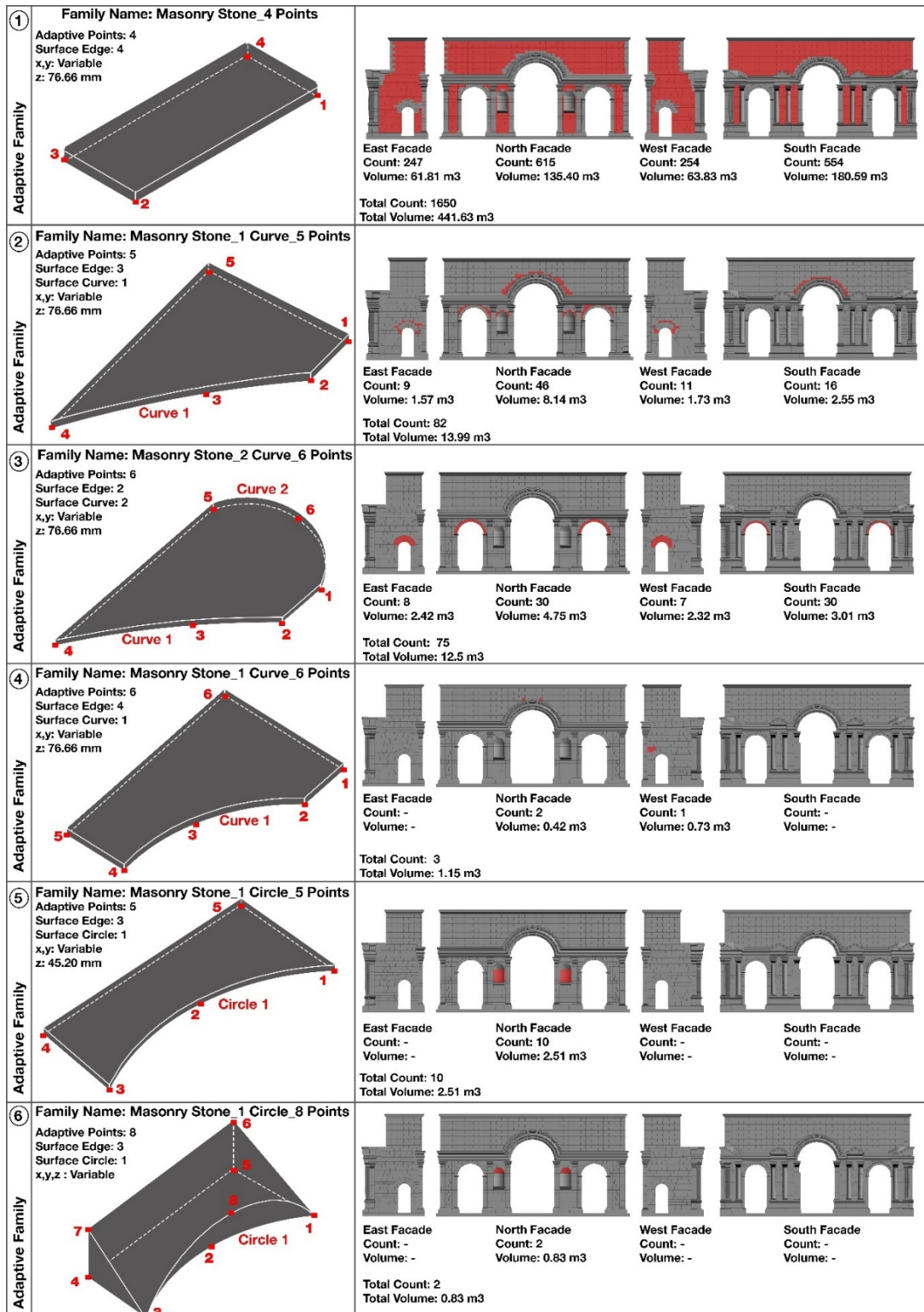


Figure 3. 55: Count, volumes, facades information of the entire adaptive family types. Source: Author's archive.

The second step of “Creating 3D Model by Referencing 2D Drawings with Developed Adaptive Components Methodology” section is Modeling of Masonry Stones of North East, South East, South West, North West Facades in Sequence and intermediate part of the structure with creating adaptive family types. In order to make a 3D HBIM model of the ATA restitution project in the Revit program, the stones on the facades are primarily modeled. The facades' intersection parts are modeled after the models of the facade stones are finished. In this section, the stones located at the intersections of the facades and in the columns of the arch section of the historical building will be modeled. In addition, stones in the middle arch parts of the building will be modeled.

Another adaptive family type to be produced to complete the HBIM model of the ATA restitution project is the 7th Adaptive family type. This adaptive family type usually forms the stones of the columns located at the intersection of the facade and the columns carrying the arches. A single adaptive family type is created especially for these stones located at facade intersections. The difference of this adaptive family type from others is that the x, y, z values are all variable. In other words, the adaptive family is designed to be moved from each point and placed at the required point. This adaptive family type has 12 straight edges and 8 adaptive points. The adaptive family type, which will form the intersections of all facades and arch columns of the project, is named according to its geometric form. Accordingly, the code system created at the beginning of the modeling is followed, and the material, edge types and point numbers are considered. This adaptive family type has 8 adaptive points (See Fig.3.56). For this, according to the code the naming of an adaptive family type consisting of 8 adaptive points and made of stone is as follows:

Adaptive Family Naming Code: Material_curve count_circle count_point count

Masonry Stone _8 Points

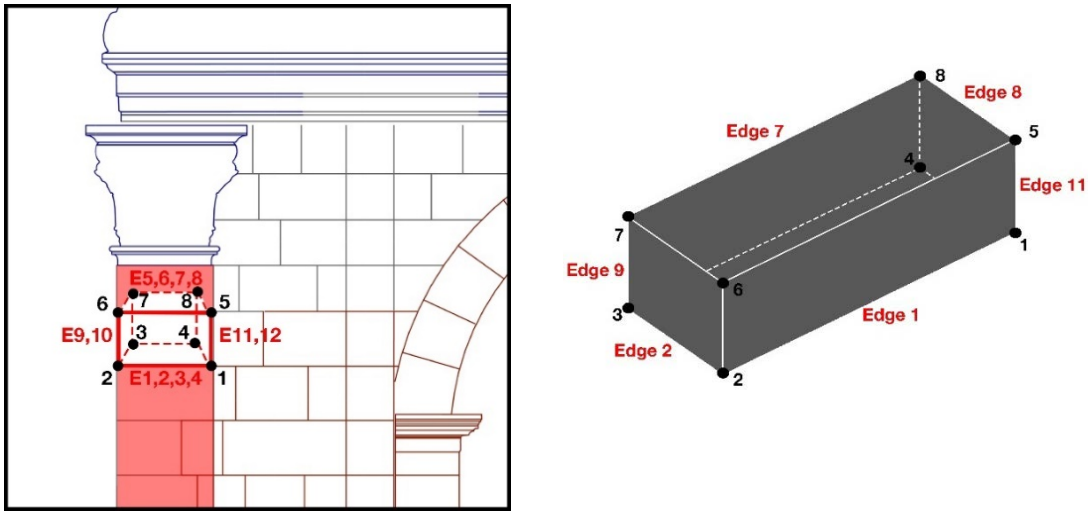


Figure 3. 56: “Masonry Stone_8 Points” adaptive family type. Source: Author's archive.

An adaptive family type named “Masonry Stone_8 Points” is produced for stones in facade intersection columns of the ATA restitution project. After the 3D HBIM Model was completed, according to the data obtained from the model, 110 pieces on the north side, 15 pieces on the west side and 36 pieces on the south side, 14 pieces of adaptive family type “Masonry Stone_8 Points” are used on the east side. In addition, the “Masonry Stone_8 Points” adaptive family type covers a volume of 0.61 m³ on the East facade, 22.12 m³ on the North facade, 1.26 m³ on the West façade and 12.99 m³ on the South facade. According to these numbers, the total number of “Masonry Stone_8 Points” adaptive family types used in the project is 175 pieces. The total volume of the “Masonry Stone_8 Points” adaptive family type covered in the project is 36.98 m³. “Masonry Stone_8 Points” adaptive family type, which has 8 adaptive points and 12 surface edges, is the 2nd most common family type in the adaptive family type in the project (See Fig.3.57).

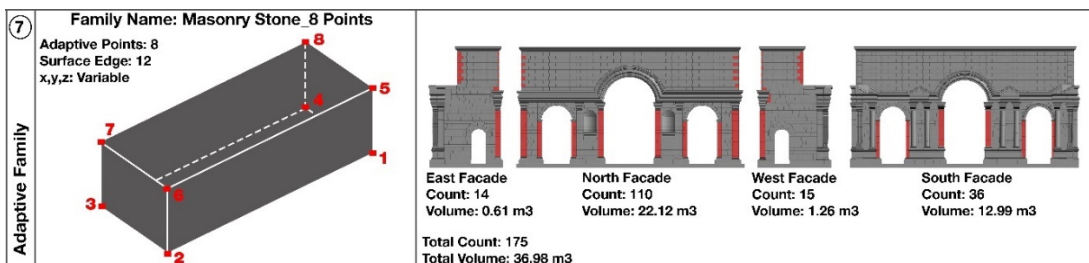


Figure 3. 57: Count, volumes, facades information of “Masonry Stone_8 Points” adaptive family type. Source: Author's archive.

"Masonry stone_8 points" is loaded into the project after the adaptive family type is created. The placement of masonry stone_8 points adaptive family type, which generally forms the column stones at the facade intersections of the project, on the points within the project is different from other adaptive family types. These column stones connecting the two facades in the project continue behind the facade as they appear on the facade. Since the "Masonry stone_8 points" adaptive family type has 8 adaptive points, it has to hold each corner of the stone. Placing the adaptive family type on the points visible on the facade has been similar to the others. However, it is very difficult to place it in the back corners. For this, the adaptive family can first be placed on the adaptive points at the back and then placed on the front points. If the placement order of the adaptive family starts from the front, the spots on the back will not appear, and the adaptive family may be placed in the wrong points. If this sequence is followed on each front, the difficulties during modeling will be reduced. Besides, in part between the column ending level of the facades and the ceiling starting level, the facade stones intertwined and come together. Here, it is determined which of the cornerstones that previously intertwined with each other belongs to which facade. Because in the "Semantic Data Entry to Revit" part of the thesis, information about which facade the stones belong will be entered and explained in detail. Since each facade is modeled as a mass in itself, it is complicated to make changes later. It is determined at the beginning of the project which facade the cornerstones belong to, and the model is created accordingly (See Fig.3.58).

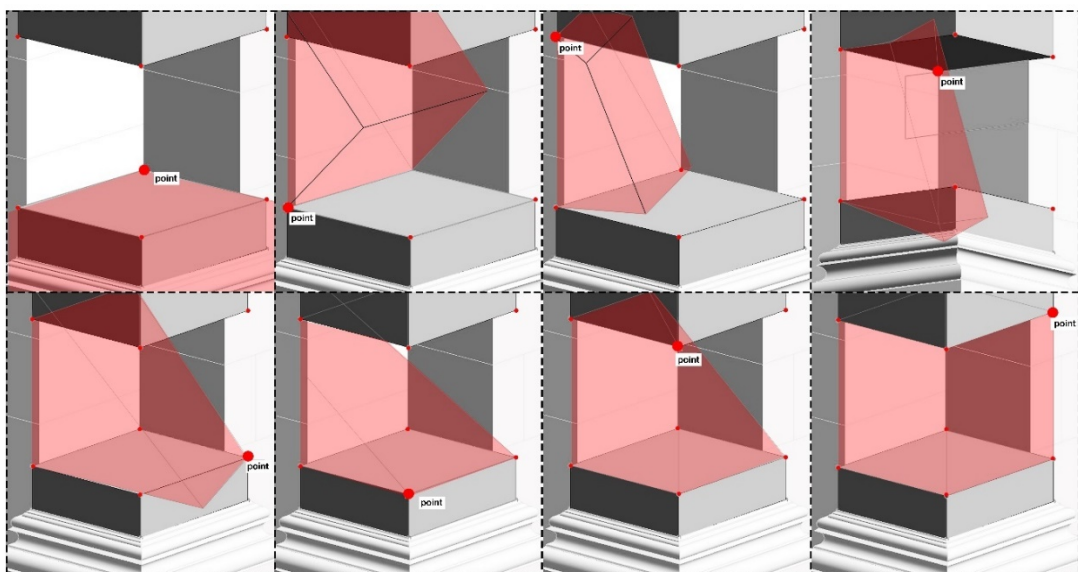


Figure 3. 58: Placing “Masonry Stone_8 points” into the model. Source: Author's archive.

In this section, after the stones at the intersections of the facades and the columns of the arches are modeled, the stones in the intermediate parts of the building will be modeled. The intermediate part of the building is modeled based on the section drawings in the ATA restitution project. Since there is no information about the stone arrangement of the arches in the intermediate part of the building, this section is modeled as a single piece with "model in-place" and "generic model."

The third step of the "Creating 3D Model by Referencing 2D Drawings with Developed Adaptive Components Methodology" section is Modeling of Column, Arch, Roof, Floor, Triangular Pediments with Generic Model. The structural elements to be explained in this part of the thesis are not directly the subject of this thesis. After the masonry stones of the historical structure are modeled, other structural elements are also modeled to maintain the integrity of the building. However, the method has not been determined for modeling these parts of the building. Apart from the masonry stones, the parts to be modeled in the building are listed as follows: Roof, Column, Floor, Arch and Triangular Pediments in aedicula parts. Complex geometries and ornaments are quite abundant in these parts of the building. For this reason, these elements are modeled quite simply based on contour lines. Because they are outside the scope of the thesis and in order not to increase the project size. Ornaments and reliefs on Corinthian column heads, arch stones and triangular pediments are ignored in the modeling process. Except for modeling the floor of the building, all building elements are modeled with "model in-place" and "generic model" (See Fig.3.59).

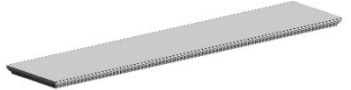


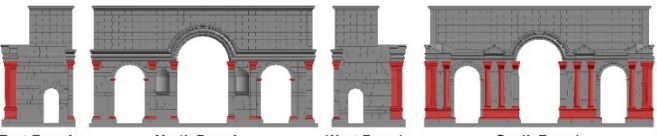
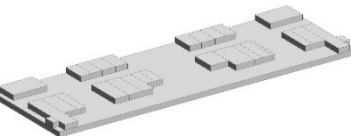


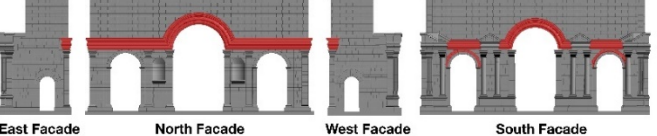

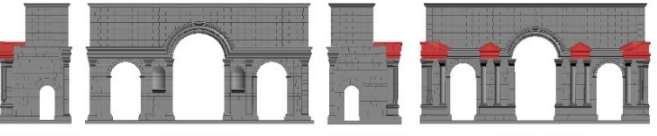
① Generic Model	<p>Generic Model Name: Roof</p> 	 <p>East Facade North Facade West Facade South Facade</p> <p>Total Volume: 130.01 m3</p>
② Generic Model	<p>Generic Model Name: Column</p> 	 <p>East Facade North Facade West Facade South Facade</p> <p>Total Volume: 75.19 m3</p>
③ Generic Model	<p>Generic Model Name: Floor</p> 	 <p>East Facade North Facade West Facade South Facade</p> <p>Total Volume: 223.44 m3</p>
④ Generic Model	<p>Generic Model Name: Arch</p> 	 <p>East Facade North Facade West Facade South Facade</p> <p>Total Volume: 67.47 m3</p>
⑤ Generic Model	<p>Generic Model Name: Triangular Pediments</p> 	 <p>East Facade North Facade West Facade South Facade</p> <p>Total Volume: 41.01 m3</p>

Figure 3. 59: Name, volume, facade information of the building elements.
Source: Author's archive.

In the ATA restitution project, some parts need to be considered in the modeling process of building elements other than masonry stone. The current situation of the building elements in the 2D Autocad drawings of the project is expressed with colors. 3 different colors are used to define the current state of the building elements. Structural elements are divided into 3 groups as in situ blocks, inventory blocks and undetectable blocks. Also, the 3 different determined colors represent these 3 groups. Before this historical structure is modeled in the Revit program, these groups and colors are considered. For this reason, while modeling the structural elements in the

project, the current situation is categorized and modeled according to what color it is expressed. Therefore, while creating a Mass model in the project, it is categorized according to the current state of the building elements, even if the structure element functions are the same. For example, a column belonging to the inventory block group and another column belonging to the insitu group cannot be in the same mass model.

3.2.5 Semantic Data Entry to Revit

The following step after “Creating 3D Model by Referencing 2D Drawings with Developed Adaptive Components Methodology” to rebuild the Anavarza/Anazarbus Triumphal Arch restitution project in Revit is Semantic Data Entry to Revit. In this part of the thesis, the process of analyzing the non-geometric data of the geometrically modeled structure and defining these data to the structural elements in Revit will be explained. In this process, firstly, the non-geometric data in the ATA restitution project are analyzed. The next step after the analysis is how these data will be transferred to the Revit program and how it will appear in the schedule section, which is the final phase of the thesis. After examining the 2D drawings of the historical building, 4 different semantic data are analyzed. These are as follows in order.

-Mark/Code

-Material

-Facade

-Comment-Image

Structural codes are the first semantic data type to be analyzed in the ATA Restitution project. In the 2D drawings of the historical building, determining building elements are coded and specified on the drawing. According to the 2D drawing, while code is not specified in the insitu block group, codes are specified in all blocks with inventory and codes are specified in some of the blocks that cannot be detected. According to the coding system in this 2D drawing, the code information is transferred to the building elements in Revit. After the building elements are modeled in Revit, the code information of the elements is entered in the "mark" parameter section in the properties panel. At this point, new parameters can actually be generated, as well as the parameters included in the program by default in the Revit program. Within this

project's scope, instead of generating a new parameter, it is preferred to use the "mark" parameter found by default in the program (See Fig.3.60).

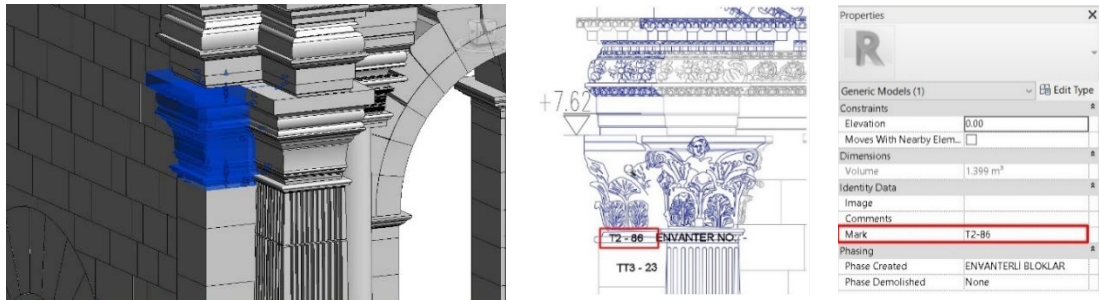


Figure 3. 60: Entering mark/code data into the properties panel. Source: Author's archive.

Structural materials are the second semantic data type to be analyzed in the ATA Restitution project. When the project drawings of the historical building are examined, 3 different materials are encountered. These materials are cut stone and profiled stone materials to be applied for the missing stone parts of the structure. The filling material inside the masonry stones is specified as lime mortar rubble filling in the drawings. After modeling the building elements, the material information of the building elements is transferred to the program according to the analyzed material information. There is no "material" section in the properties panel by default in the Revit program for the generated Adaptive families. For adaptive family types, the material parameter can be added later by the user, and each material to be used in the project is created with its properties from the material library. First of all, a material parameter is created for adaptive family types. For this, there is a specified material parameter inside the adaptive family. However, the material to be assigned to 1 adaptive family type affects all the elements formed with this adaptive family type in the project. All stones belonging to that adaptive family type become the same material. For example, the adaptive family type named "masonry stone_4 points" is used both on the north and south facades, but the material can be different on both sides in the project. In such a case, it is decided that the assigning material in the adaptive family is not correct. After loading adaptive family into the project, the material parameter assignment by the user in the mass family is correct within this project's scope. For this reason, changes are not made inside the adaptive family, and the material section in the properties panel is left as "by category" by default.

The masonry stones created with adaptive family types are included in the project as a separate category as a mass. The features of each element in the Mass can be different in the properties panel. The data entered into each stone in the same Mass can be different from each other. There are graphics, dimensions, identity data, adaptive components and other parameters when the default parameters in the Properties panel in the Revit program are examined. Since there is no "material" parameter in the properties panel by default, the material parameter is added to the properties panel later. A new parameter is added to the project from the "manage" tab and "project parameters" section (See Fig.3.61).

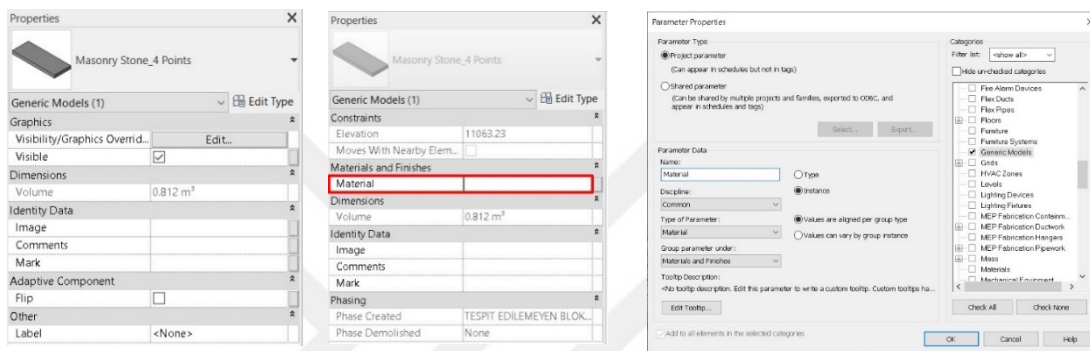


Figure 3. 61: Creating material parameter and assigning material to building elements. Source: Revit user interface.

Materials are assigned to the modeled building elements, with the material parameter added later in the mass. In this section, there are also default parameters for entering material information comprehensively into the building elements. These parameters are identity, graphics and appearance data parts. Detailed data on the feature of the materials can be entered in these parameter sections. However, since there is no detailed information about the material to be used in the restitution project of the historical building in this project, these sections are left blank in the scope of this thesis. Only the materials of the modeled building elements are created and assigned to the building elements. The default parameters in the material library are essential for the comprehensiveness of the material information. This section contains the material's physical properties, its appearance within the project, the manufacturer, its code, price, URL address, and all the settings required for rendering (See Fig.3.62).

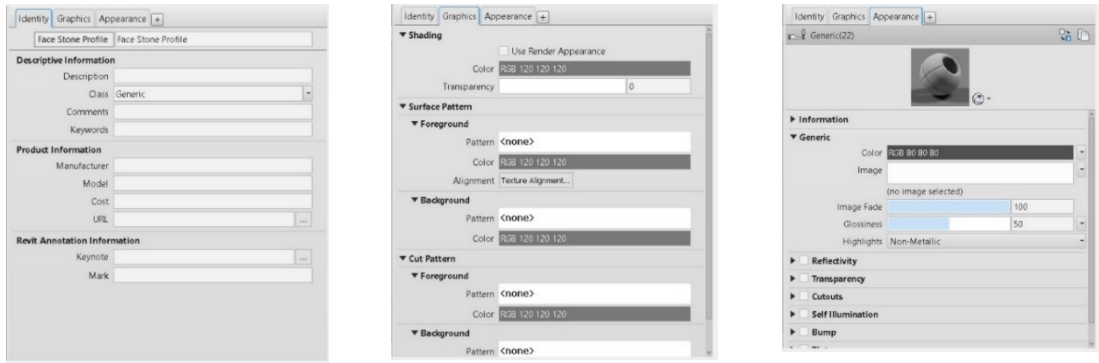


Figure 3. 62: Material properties. Source: Revit user interface.

Facade information on which building elements are located is the third semantic data type to be analyzed in the ATA Restitution project. This information is not a part specified in the 2D drawings of the building. It is a parameter created in the Revit program to access masonry stones and categorize them more easily in the schedule section. Building elements on different facades can be categorized owing to this parameter created in the Revit program. It is aimed to reach information such as how many different materials are used on a facade, how many adaptive family types are used, the count of stones used or the volume they cover. A new parameter can be created, or default parameters can be used as described in the previous section for information on which facade the masonry stones of the historical building belong to. In this project, a new parameter named "facade" is created in the identity data section and the façade information of the building elements is entered in this section (See Fig.3.63).

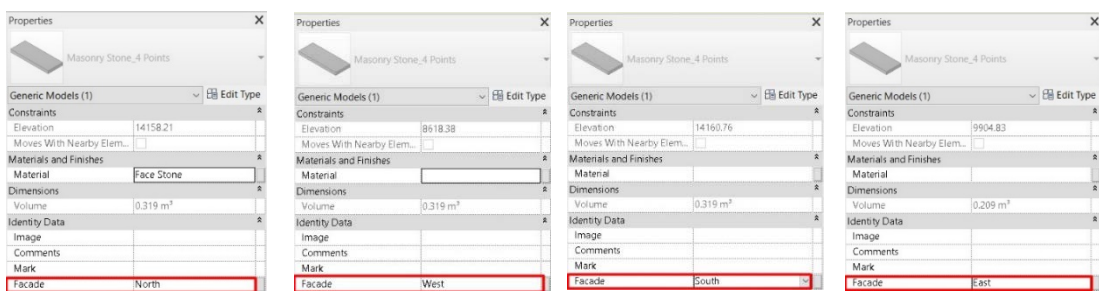


Figure 3. 63: Facade information of masonry stones. Source: Revit user interface.

Comment and image are the fourth semantic data type to be analyzed in the ATA Restitution project. Comment and image parameters are included in mass by default. There is a "comment" parameter to enter information about the specific conditions of the building elements in the projects or write a comment. The image parameter is used

to photograph historical building elements and record them in the project. This information about the building elements transferred to the project with parameters is included in the documentation section's last step of the project. These parameters could not be used since there is no comment on any building element on this project, and there are no photographs of the building elements.

3.2.6 Categorization of the Elements and Phases

The following step after “Semantic Data Entry to Revit” to rebuild the ATA restitution project in Revit is the Categorization of the Elements and Phases. In this section, the current status of the building elements will be examined based on the drawings of the building and will be transferred to the system. The current state of the structure elements, which were briefly mentioned in the previous sections of the thesis, will be explained in detail in this section. In the 2D drawings of the ATA Restitution Project, the states of the building elements are expressed in legend with colors. Building elements are divided into 3 categories in the drawings of the project, and each is represented by a different color. These categories are insitu blocks, undetectable blocks and inventory blocks. Each building element in the project belongs to one of these 3 blocks. It is categorized and expressed by the color in which it is represented accordingly.

"Phase" command is used in the Revit program to categorize the current state of the building elements in the project. Time data is added to the project with the Phase command. It can be organized in a single model with the phase command for the parts that will be demolished in the project, the parts to be renovated, and the parts to be reconstructed additionally over time without creating separate models. In short, a new time dimension is added to the 3-dimensional project with the phase command, and it is turned into a 4-dimensional project. In the Revit program, there are "Existing" and "New Construction" stages by default in the phase section. The designer can add new stages to this part or edit the stages included by default. Each element created in the project has phase information in the properties panel. If a new phase is not assigned to the created building element, "new construction" is the default in the phase section of the properties panel.

Within the scope of this thesis, 3 different phases are created with the names of insitu blocks, undetectable blocks and inventory blocks in the ATA restitution project. Insitu

blocks represent the elements that exist today, Inventory blocks represent the identified and recorded building elements. Finally, the undetectable blocks represent the building elements that cannot be identified. All the building elements belonging to the same category, which are briefly mentioned in the previous stages of the thesis, are modeled as separate mass models, so they can be accurately categorized at this stage. Each block type is expressed in different colors in the restitution drawing of the project. The blocks created as 3 different phases in the Revit program are also expressed with the same colors specified in the Autocad. Insitu blocks are expressed in red, inventory blocks in blue, and undetectable blocks in gray. 3 different phases are created with the phase command under the manage tab in Revit and colored with the "Graphic Overrides" command (See Fig.3.64). In this section, the material of the model, line types in appearance and section, their thickness and colors can be adjusted in the technical drawing appearance. When required, the blocks to be displayed on the screen can be adjusted from the "phase" and "phase filter" section in the Properties panel (See Fig.3.65).

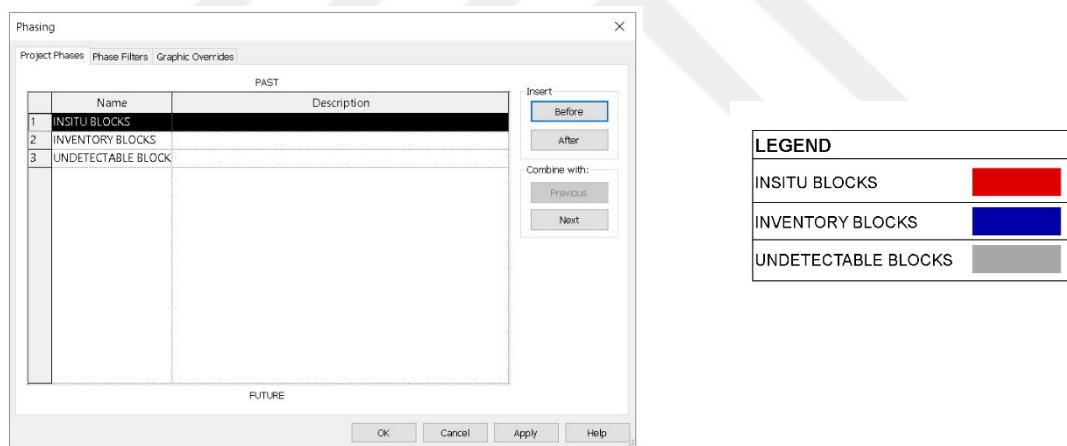


Figure 3. 64: Phasing settlement. Source: Author's archive.

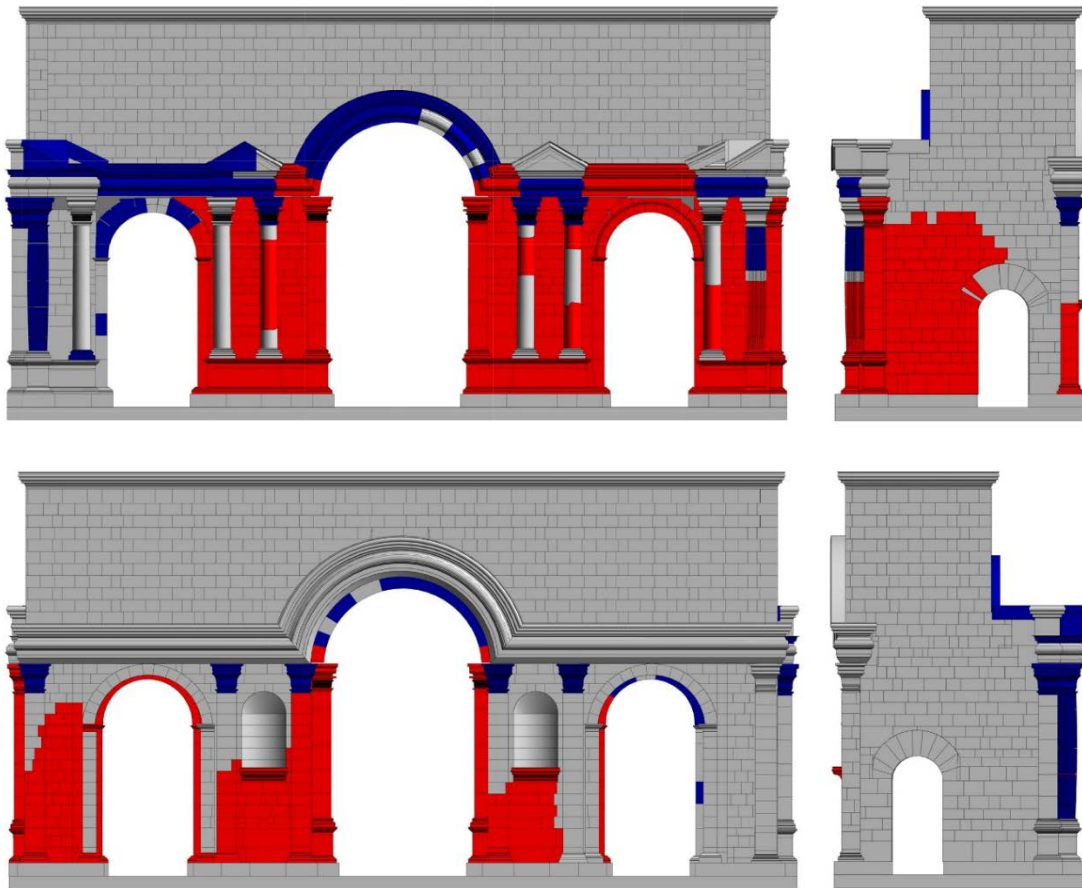


Figure 3. 65: Current status of south, east, north, west facade. Source: Author's archive.

3.2.7 Documentation

The following step after “Categorization of the Elements and Phases” is “Documentation.” In this section, written documents are created in the form of tables of all geometric and non-geometric data added to the project until this stage. The document created in the Schedule/Quantities section of Revit contains detailed geometric and non-geometric information about the building elements modeled in the project. Each element in the historical structure has a counterpart with its features in the schedule section. In this section, the designer determines the data types to be included in the document. All information entered into the building elements during the project can be obtained in written form from the schedule section at the end of the project.

In the scope of this thesis, information of family name, count, ID, volume material, facade and phase of the building elements are included in the schedule section, respectively in the ATA Restitution project. Building elements with all different

properties and information are categorized according to their facades. With the schedule in Revit, how many types of adaptive families are used on which facade, the total volume of all adaptive families, the ID of the building elements, the material of each element on the facade, and finally, the phase of each of the building elements can be accessed.

The schedule section is an important section that not only provides a document containing geometric and non-geometric properties of the building elements, but also enables the model to be controlled. To give an example to this situation, it is complicated to select the masonry stones belonging to many different adaptive family types on one facade on the historical building. This is because masonry stones are from different family types. There are simple methods for selecting elements of the same type in the Revit program. However, it is challenging to select all masonry stone stones on the same facade with these methods. Because there are various masonry stones from different adaptive family types on a single facade. Thus, the schedule part is used to make this selection in Revit. For this, the elements on the same facade in the schedule are categorized and selected collectively. Then, using the "highlighted in model" command, all the elements on the same facade of the model are selected at once. In addition, a revision on the non-geometric properties of the building elements can be easily performed within the schedule. To give an example, if it is necessary to change the materials of the stones on the facade later, and if there are many different family types on the facade, the materials of the elements can be changed quickly by selecting the necessary elements from the material parameter via Schedule. As a result, the data entered into the building elements during the modeling process in Revit is obtained as documentation from the schedule section in a processed form (See Fig.3.66).

ANAVARZA/ANAZARBOS TRIUMPHAL ARCH RESTITUTION PROJECT SCHEDULE						
FAMILY	COUNT	ID	VOLUME	MATERIAL	FACADE	PHASE
Roof	1	T2-111,113,14; TT2-88,27,95; T3-91	130.01 m³	Profile Stone		UNDETECTABLE BLOCKS
Floor	1		223.44 m³	Profile Stone		INVENTORY BLOCKS
East						
North East Column 1_Stone 1	1		0.47 m³	Profile Stone	East	INSITU BLOCKS
North East Column 1_Stone 2	1		0.61 m³	Profile Stone	East	INSITU BLOCKS
North East Column 1_Stone 3	1		0.90 m³	Profile Stone	East	INSITU BLOCKS
North East Column 1_Stone 4	1		1.09 m³	Profile Stone	East	INSITU BLOCKS
North East Column 1_Stone 5	1		0.31 m³	Profile Stone	East	INSITU BLOCKS
North East Column 2	1		1.70 m³	Profile Stone	East	INSITU BLOCKS
Masonry Stone_1 Curve_5 Points	6		0.86 m³	Face Stone	East	INSITU BLOCKS
Masonry Stone_1 Curve_5 Points	4		0.81 m³	Face Stone	East	UNDETECTABLE BLOCKS
Masonry Stone_2 Curve_6 Points	2		0.98 m³	Face Stone	East	INSITU BLOCKS
Masonry Stone_2 Curve_6 Points	4		1.35 m³	Face Stone	East	UNDETECTABLE BLOCKS
Masonry Stone_4 Points	75		19.89 m³	Face Stone	East	INSITU BLOCKS
Masonry Stone_4 Points	172		41.92 m³	Face Stone	East	UNDETECTABLE BLOCKS
Masonry Stone_8 Points	14		0.61 m³	Face Stone	East	UNDETECTABLE BLOCKS
Intermediate Section						
Intermediate Filling 1	1		80.30 m³	lime mortar rubble filling	Intermediate Section	UNDETECTABLE BLOCKS
Intermediate Filling 2	1		78.72 m³	lime mortar rubble filling	Intermediate Section	UNDETECTABLE BLOCKS
Intermediate Filling 3	1		38.61 m³	lime mortar rubble filling	Intermediate Section	UNDETECTABLE BLOCKS
Intermediate Filling 4	1		34.78 m³	lime mortar rubble filling	Intermediate Section	UNDETECTABLE BLOCKS
Masonry Stone_1 Curve_5 Points	63		11.11 m³	Face Stone	Intermediate Section	UNDETECTABLE BLOCKS
Masonry Stone_1 Curve_6 Points	12		3.37 m³	Face Stone	Intermediate Section	UNDETECTABLE BLOCKS
Masonry Stone_2 Curve_6 Points	45		12.75 m³	Face Stone	Intermediate Section	UNDETECTABLE BLOCKS
Masonry Stone_4 Points	1		1.65 m³	Face Stone	Intermediate Section	INSITU BLOCKS
Masonry Stone_4 Points	254		70.40 m³	Face Stone	Intermediate Section	UNDETECTABLE BLOCKS
Middle Arch 1	1		856.80 m³	lime mortar rubble filling	Intermediate Section	UNDETECTABLE BLOCKS
Middle Arch 2	1		33.00 m³	lime mortar rubble filling	Intermediate Section	UNDETECTABLE BLOCKS
Middle Arch 3	1		32.96 m³	lime mortar rubble filling	Intermediate Section	UNDETECTABLE BLOCKS
North						
Adaptive family_6 points	1		0.04 m³		North	INSITU BLOCKS
North West Column 1	1		0.88 m³	Profile Stone	North	UNDETECTABLE BLOCKS
North West Column 2	1		0.50 m³	Profile Stone	North	INSITU BLOCKS
North West Column 3	1		0.38 m³	Profile Stone	North	INSITU BLOCKS
North West Column 4	1		0.38 m³	Profile Stone	North	INSITU BLOCKS
North West Column 5	1		0.38 m³	Profile Stone	North	UNDETECTABLE BLOCKS
North West Column 6	1		0.38 m³	Profile Stone	North	INSITU BLOCKS
North Facade Arch	1	T3-92,45,30, 76; TT2-85,89,44; T2-98; T1-16,12,13	25.38 m³	Profile Stone	North	UNDETECTABLE BLOCKS
North Facade Detail 1	1		1.19 m³	Profile Stone	North	INSITU BLOCKS
North Facade Detail 2	1		1.19 m³	Profile Stone	North	INSITU BLOCKS
North Facade Column Beginning 1	1		0.29 m³	Profile Stone	North	INSITU BLOCKS
North Facade Column Detail 1	1		0.11 m³	Profile Stone	North	INSITU BLOCKS
North Facade Column Detail 2	1		0.11 m³	Profile Stone	North	UNDETECTABLE BLOCKS
North Facade Column Detail 3	1		0.11 m³	Profile Stone	North	UNDETECTABLE BLOCKS
North Facade Column Detail 4	1		0.11 m³	Profile Stone	North	UNDETECTABLE BLOCKS
North Facade Column Beginning 2	1		0.29 m³	Profile Stone	North	INSITU BLOCKS
North Facade Column Beginning 3	1		0.30 m³	Profile Stone	North	UNDETECTABLE BLOCKS
North Facade Column Beginning 4	1		0.29 m³	Profile Stone	North	UNDETECTABLE BLOCKS
North Facade Column Head 1	1	T2-84	1.01 m³	Profile Stone	North	INVENTORY BLOCKS
North Facade Column Head 2	1	T3-24	1.01 m³	Profile Stone	North	INVENTORY BLOCKS
North Facade Column Head 3	1	T2-11	1.01 m³	Profile Stone	North	INVENTORY BLOCKS
North Facade Column Head 4	1	T2-16	1.01 m³	Profile Stone	North	INVENTORY BLOCKS
North Facade Column Head 5	1	T1-39	1.01 m³	Profile Stone	North	INVENTORY BLOCKS
North Facade Column Head 6	1		1.01 m³	Profile Stone	North	UNDETECTABLE BLOCKS
Masonry Stone_1 Circle_5 Points	10		2.51 m³	Face Stone	North	INSITU BLOCKS
Masonry Stone_1 Circle_8 Points	2		0.73 m³	Face Stone	North	INSITU BLOCKS
Masonry Stone_1 Curve_5 Points	50		8.97 m³	Face Stone	North	UNDETECTABLE BLOCKS
Masonry Stone_1 Curve_6 Points	2		0.42 m³	Face Stone	North	UNDETECTABLE BLOCKS
Masonry Stone_2 Curve_6 Points	9		1.49 m³	Face Stone	North	INSITU BLOCKS
Masonry Stone_2 Curve_6 Points	21		3.24 m³	Face Stone	North	UNDETECTABLE BLOCKS
Masonry Stone_4 Points	101		20.48 m³	Face Stone	North	INSITU BLOCKS
Masonry Stone_4 Points	523		115.85 m³	Face Stone	North	UNDETECTABLE BLOCKS
Masonry Stone_8 Points	41		9.04 m³	Face Stone	North	INSITU BLOCKS
Masonry Stone_8 Points	74		13.67 m³	Face Stone	North	UNDETECTABLE BLOCKS

South						
South Facade Column Head 1	1	T2-86	1.40 m ³	Profile Stone	South	INVENTORY BLOCKS
South Facade Column Head 2	1		1.40 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Column Stone 1	1		2.14 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Column Stone 2	1		1.95 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Column Beginning 1	1	T3-77	0.31 m ³	Profile Stone	South	INVENTORY BLOCKS
South Facade Column 1	1		2.85 m ³	Profile Stone	South	INVENTORY BLOCKS
South Facade Column Stone Ending 1	1		0.91 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Column Ending Detail 1	1		1.26 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Arch 1	1	T3-38,44,43; T2-42,115,11 7,43,46,47; TT3-94,78, T1-14	22.44 m ³	Profile Stone	South	INVENTORY BLOCKS
South Facade Arch 2	1		15.36 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Arch 3	1	T1-20	1.17 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Column 2	1	T1-34	7.12 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Column 3	1	TT1-31, 31a, 32, 33	3.90 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Column Beginning 2	1		1.48 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Column Ending Detail 2	1		2.65 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Column Stone Ending 2	1		6.61 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Column Ending Detail 3	1	TT1-27,24; T3-96	5.02 m ³	Profile Stone	South	INVENTORY BLOCKS
South Facade Triangular Pediments 1	1		15.44 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Column Head 3	1	T2-18; T2-82; T3-93	3.38 m ³	Profile Stone	South	INVENTORY BLOCKS
South Facade Column Stone Ending 3	1		1.73 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Column Ending Detail 4	1	T3-26	2.20 m ³	Profile Stone	South	INVENTORY BLOCKS
South Facade Column Beginning 3	1		4.59 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Triangular Pediments 2	1	T1-5; T1-36	2.37 m ³	Profile Stone	South	INVENTORY BLOCKS
South Facade Column Head 4	1	T2-84	3.38 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Triangular Pediments 3	1	TT1-1; T3-37;	10.38 m ³	Profile Stone	South	INVENTORY BLOCKS
South Facade Column Ending Detail 5	1	T3-14	2.82 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Column Ending Detail 6	1		1.85 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Triangular Pediments 4	1		1.51 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Column Head 5	1		2.51 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Arch 4	1		0.04 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Arch Stone 1	1		1.54 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Column Ending Detail 6	1		0.43 m ³	Profile Stone	South	INSITU BLOCKS
South Facade Arch Stone 2	1		1.35 m ³	Profile Stone	South	INVENTORY BLOCKS
South Facade Column Ending Detail 7	1		0.14 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
Güney Cephe Sol kemer Üst Taslar	1		0.19 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South Facade Arch Stone 3	1		0.26 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South East Facade Column Stone 1	1	TT1-38 ; TT3-22	1.01 m ³	Profile Stone	South	INVENTORY BLOCKS
South East Facade Column Stone 2	1		2.98 m ³	Profile Stone	South	INSITU BLOCKS
South West Facade Column Stone 1	1		1.43 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South West Facade Column Stone 2	1	TT1-37	0.47 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South West Facade Column Stone 3	1	TT3-18	0.61 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South West Facade Column Stone 4	1	TT3-19	0.90 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South West Facade Column Stone 5	1	TT3-21	1.09 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South West Facade Column Stone 6	1	TT3-23	0.31 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
South West Facade Column Stone 7	1		1.70 m ³	Profile Stone	South	UNDETECTABLE BLOCKS
Masonry Stone_1 Curve_5 Points	16		2.55 m ³	Face Stone	South	UNDETECTABLE BLOCKS
Masonry Stone_2 Curve_6 Points	18		1.81 m ³	Face Stone	South	INSITU BLOCKS
Masonry Stone_2 Curve_6 Points	10		1.00 m ³	Face Stone	South	INVENTORY BLOCKS
Masonry Stone_2 Curve_6 Points	2		0.20 m ³	Face Stone	South	UNDETECTABLE BLOCKS
Masonry Stone_4 Points	134		64.80 m ³	Face Stone	South	INSITU BLOCKS
Masonry Stone_4 Points	470		125.49 m ³	Face Stone	South	UNDETECTABLE BLOCKS
Masonry Stone_8 Points	28		11.00 m ³	Face Stone	South	INSITU BLOCKS
Masonry Stone_8 Points	1	T2-79	0.31 m ³	Face Stone	South	INVENTORY BLOCKS
Masonry Stone_8 Points	7		1.68 m ³	Face Stone	South	UNDETECTABLE BLOCKS
West						
Masonry Stone_1 Curve_5 Points	10		1.51 m ³	Face Stone	West	UNDETECTABLE BLOCKS
Masonry Stone_1 Curve_6 Points	1		0.73 m ³	Face Stone	West	UNDETECTABLE BLOCKS
Masonry Stone_2 Curve_6 Points	7		2.32 m ³	Face Stone	West	UNDETECTABLE BLOCKS
Masonry Stone_4 Points	253		63.33 m ³	Face Stone	West	UNDETECTABLE BLOCKS
Grand total: 2526	2526		2315.49 m ³			

Figure 3. 66: Anavarza/Anazarbus Triumphant Arch Restitution Project Schedule. Source: Author's archive.



4. RESULT and DISCUSSION

Historical buildings accumulate cultural, social, material, and structural layers during their survival. Conserving and documenting the historical buildings is imperative to preserve the historical heritage. New mediums and systems are emerging with technological developments to conserve historical heritage. BIM system is one of these new technological developments. Since the Building Information Modeling system existed in the AEC industry, design, production, and management processes changed direction. It can be said that this system offers different perspectives in new building design, production and management processes. It is predicted that this system can also benefit historical buildings. This system, which emerged as the concept of HBIM, is useful for conserving or re-functioning historical structures. In the platforms used in the BIM system, each new building element is created in the form of smart objects, and each of these objects is interconnected, establishes a basis for future stages. In new buildings, it is much easier to create each object parametrically and construct the relationship with other objects than historical building elements. Because the complex form of the building elements included in the new buildings is simpler compared to historical building elements. A specialist in this regard carries out some studies to make the HBIM process more practical. A historical building selected as a case study is produced within the scope of HBIM using the Autodesk Revit software throughout this thesis. This thesis aims to examine the potential possibilities of on available methods provided in Revit for the reconstruction of the non-uniformly deteriorated masonry wall of the historical building with smart objects within the scope of HBIM.

In this study, a modeling methodology development study was carried out to conserve historical buildings by using Autodesk Revit software. 2 different methods are conducted in the Revit program to produce the non-uniformly deteriorated masonry walls of historical buildings in the HBIM system. After the appropriate method is determined, studies continued on the historical structure selected as a case study. Firstly, it tested on only one sample non-uniformly deteriorated masonry wall. This

wall is parametrically modeled in Revit software with the developed HBIM modeling methodologies. Stone elements of masonry wall modeling experiments are carried out using the Metric Generic Model Pattern Based Family and Metric Generic Model Adaptive Family. At the end of the experiment, the positive and negative aspects of two different methods of the HBIM process were discussed. The first of the two methods studied for the masonry stone wall model is the "Metric Generic Model Pattern Based Family" type. It is observed that the dimension of the stones of the sample wall created by this method is stable. Non-standard actual stone dimensions in historical buildings could not be created in 3D using this method. It is decided not to use this method because the wall created with this family type consists of stones with uniform dimensions and non-flexible forms. The second method is the "Metric Generic Model Adaptive Family" type. It is observed that the dimension of the stones of the sample wall created by this method is unstable. Non-standard actual stone dimensions in historical buildings could be created in 3D using this method. In addition, each stone can carry its geometric and non-geometric properties separately on them with this method. In this way, it is possible to document each stone separately. It is decided to use this method because the wall created with this family type consists of adaptable stones, is flexible and can be easily edited.

Stone modules that can adapt to each other can be created by using the Generic Model Adaptive Family. When one of the modules connected to each other with adaptive point points is moved, other modules connected to it move in the same axis. In this way, all elements of the masonry stone wall connect with each other and move together. All of the smart building objects modeled with this methodology are created accurately in 3D with the historical building reference. The as-built model, where geometric and non-geometric information is also integrated, contains all the necessary data for the historic building. Within the scope of this thesis, it was decided to produce the Anavarza/Anazarbus Triumphal Arch Restitution Project with a "generic model adaptive family". Each element of the ATA in this study will be modeled parametrically in accordance with the HBIM system. All kinds of geometric and non-geometric data about historical building elements will be transferred to the system. This system construction is carried out by examining the potential possibilities of on available methods provided in Revit within the scope of HBIM. This thesis, which creates the process of a historical building from 2D drawing to 3D HBIM model,

completes the deficiency in the literature due to its difference and sheds light on future studies.

Historical buildings contain a variety of materials, and each of them has different construction techniques. Various methods can be investigated in the case of HBIM modeling in historical buildings with different materials and construction techniques. The scope of this thesis topic is limited to the stone material and masonry construction method. The aim is to model the masonry stone walls of historical buildings with an adaptive family in the Revit program. ATA structure masonry stones are modeled with the researched and tested method for this. However, this method is only valid for structures built with stone materials and masonry techniques. It is researched and applied for a specific material and form of construction. For this reason, it is not enough to create the HBIM model of every historical building.

The historical structure transferred to the digital environment using different modeling programs is just a “model” in the literature. On the other hand, in the HBIM system, the historical building is not just a model with the smart objects created by processing the numerical data from the building. The HBIM system is the greatest requirement to have smart objects with geometric and non-geometric data. If all the elements of the building are produced parametrically, the BIM system can be used in the analysis of the structure in future predictions and simulations. Because in this way, the identification of each object in the HBIM model is registered in the system. It does not comply with the HBIM system due to the lack of smart objects and geometric and non-geometric data entries in 2D drawings and 3D models. It is vital to understand, analyze and digitize the features of the historic structure in the HBIM system. In this way, conservation, recording and analysis studies of each historical building generated within the scope of HBIM with smart objects can be carried out.

Modeling each historical structural element interconnected with smart objects creates an HBIM model in its entirety. The existence of HBIM models of historical buildings sheds light on future studies on the structure and suggestions. Future studies to be applied to historical buildings may differ based on future technology. However, future studies of the historical buildings with the HBIM model can be predicted with today's technology. One of the future studies of the historical building is HBIM simulations. All elements of a historical building with an HBIM model are created with smart objects and contain geometric and non-geometric information. Using this information

and entering the relevant parameters, simulations about how the building elements will remain in the future can be generated. In this way, the future of the building can be interpreted, and provision can be made against possibilities. Another of the future studies of the historical structure is that the data repository contained in smart objects can be used with artificial intelligence. Artificial intelligence systems can be fed from the data repository embedded in the HBIM structure for future studies. The model consisting entirely of smart objects will be used to predict historic buildings made by artificial intelligence. Another future study of the historic building may be to develop a new method for the HBIM model of a historical building using different materials and material techniques. This study has only been carried out on the masonry construction technique and stone material in the digital environment as 3-Dimensional. However, even if this study is focused on a particular material and construction technique, it can be said that guiding is created for each structure with different materials and produced from unit elements. This study creates an example for 3D models of historical buildings with different materials and construction techniques. Thus, similar techniques can be developed for each material and construction technique. Construction materials can take shape at a specific level of elasticity, depending on their physical properties. According to this level difference, angular forms are obtained from particular materials, while curved forms are obtained from other particular materials. Modeling various forms physically in 3D in a digital environment may require different methods. For this reason, the 3D model of the form to be created in accordance with the nature of each material can be generated by developing various methods in the digital environment. In future studies, investigation of new methods in buildings with different materials and different construction techniques based on this study specifically for masonry stone walls will be carried out. This method is quite necessary for the innovative system applications that will be developed in the future on the historical building. It is essential to turn all elements into intelligent objects in relationship with each other by the help of parametric modeling after creating a point cloud with laser scanners. In this way, these methods will be helpful in computational studies and simulations on structural analysis, material analysis, performance, and future deterioration of the building elements and the entire structure. If artificial intelligence is developed to predict future deterioration in the

building, machine learning training can be performed on HBIM models with intelligent objects.

New ideas, new systems and different perspectives are necessary for the future and today to conserve the historical heritage. New systems developed by specialists in their fields carry history and historic buildings to the future with the aid of cutting-edge technology. With the innovative and technological systems developed by different disciplines integrated on the same platform, the past is always accessible and experienced by everyone.





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