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BIM UTILIZATION IN RESTORATION PROJECTS: MAHMUD PASHA HAMMAM

Hasan Fevzi ÇÜGEN

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ETHICAL STATEMENT

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Hasan Fevzi ÇÜGEN
11/02/2022

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(M. Sc. Thesis)

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ABSTRACT

Studies for preserving historical monuments require multi-faceted, multi-stakeholder, long and laborious processes. For this reason, can the Building Information Model approach, which offers significant advantages in the construction industry, especially in collaborative project production/delivery processes, also be used in studies to protect cultural heritage? This question is on researchers' agenda. In many studies conducted for this purpose in the literature, it is stated that existing software is used for the production of Heritage Building Information Model, and difficulties are encountered in the modeling of the current situation. In addition, the studies' experimental nature raises questions about the adequacy/reliability of the results obtained. As a result, it gives the impression that the software are not yet qualified to replace the existing methods used in documenting and projecting heritage buildings. In this study, the answers to the question of whether viable projects can be obtained by examining the usability of the Building Information Model approach within the scope of a professional/commercial restoration application project and using the existing software tools within their "purpose" were sought. In this context, this study proposes an integrated workflow model in which the new approach can be used to prepare restoration projects as an intermediate formula, thereby enhancing familiarity/coordination among stakeholders. For this purpose, Mahmud Pasha Bath, which was built in Serbia in the 15th century, was chosen as a case study. A survey model was created with the point cloud obtained by classical methods and a new usage scenario was proposed and exemplified by preparing restoration proposal alternatives using Building Information Model tools on this model. It has been seen that the proposed workflow can be a viable method to create awareness that will help increase the professional usability of the new approach to historical artifacts and evaluate the existing qualified personnel pool.

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RESTORASYON PROJELERİNDE BIM KULLANIMI: MAHMUD PAŞA HAMAMI

(Yüksek Lisans Tezi)

Hasan Fevzi ÇÜGEN

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ÖZET

Tarihi eserlerin korunması için yapılan çalışmalar çok yönlü, çok paydaşlı, uzun ve zahmetli süreçleri gerektirmektedir. Bu sebeple, yapı sektöründe özellikle koordineli proje üretim/teslim süreçlerinde önemli avantajlar sunan Yapı Bilgi Modeli yaklaşımı, kültürel mirasın korunması için yapılan çalışmalarda da kullanılabilir mi? sorusu araştırmacıların gündemindedir. Literatürde bu amaçla yapılmış birçok çalışmada, Tarihi Yapı Bilgi Modeli üretimi için mevcut yazılımların kullanıldığı ve mevcut durumun modellenmesi aşamasında zorluklarla karşılaşıldığı belirtilmektedir. Ayrıca, yapılan çalışmaların deneysel nitelikte olması, elde edilen sonuçların yeterliliği/güvenirliği konusunda soru işaretleri barındırmaktadır. Sonuç olarak, bu yazılımların henüz tarihi yapıların belgelenmesi ve projelendirilmesinde kullanılan mevcut yöntemlerin yerini alabilecek nitelikte olmadığı izlenimi vermektedir. Bu çalışmada ise, profesyonel/ticari bir restorasyon uygulama projesi kapsamında Yapı Bilgi Modeli yaklaşımının kullanılabilirliğini irdelemek ve mevcut yazılım araçlarının "amaçları" dahilinde kullanılması ile uygulanabilir projelerin elde edilip edilemeyeceği sorusunun cevapları aranmıştır. Bu bağlamda bu çalışma bir ara formül olarak restorasyon projelerinin hazırlanmasında yeni yaklaşımın kullanılabileceği ve böylece paydaşlar arasında aşinalığın/koordinasyonun pekiştirileceği entegre bir iş akışı modeli önermektedir. Bu amaçla 15.yy'da Sırbistan da yapılmış olan Mahmud Paşa Hamamı alan çalışması olarak seçilmiş, klasik yöntemlerle elde edilen nokta bulutu ile bir rölöve modeli oluşturulmuş ve bu model üzerinden Yapı Bilgi Modeli araçları kullanılarak restorasyon öneri alternatifleri hazırlanarak yeni bir kullanım senaryosu önerilmiş ve örneklendirilmiştir. Yeni yaklaşımın tarihi eserlerde profesyonel olarak kullanılabilirliğinin artırılmasına yardımcı olacak farkındalığın oluşturulabilmesi ve mevcut nitelikli personel havuzunun değerlendirilebilmesi için önerilen iş akışının uygulanabilir bir yöntem olabileceği görülmüştür.

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ABBREVIATIONS

The abbreviations used in this study are presented below with their explanations.

Abbreviation	Definition
2D	Traditional two-dimension drawing (CAD-paper)
3D	3D model
AEC	Architecture, Engineering and Construction
AI	Artificial Intelligence
BHIMM	Built Heritage Information Modeling and Management
BIM	Building Information Modeling
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CH	Cultural Heritage
CIPR	Chartered Institute of Public Relations
CSV	Comma-Separated Values File
DWG	Drawing (file format for 2D-3D design data and metadata.)
DXF	Drawing Interchange (or Exchange) Format
FEM	Finite Element Modeling
FM	Facility Management
GDL	Geometric Description Language
GIS	Geographic Information Systems
GOG	Grade of Generation
HBIM	Heritage Building Information Modeling
ICCROM	The International Centre for the Study of the Preservation and Restoration of Cultural Property
ICOMOS	International Council on Monuments and Sites
ICT	Information and Communications Technologies
IFC	Industry Foundation Classes
LC	Life Cycle
LIDAR	Laser Imaging Detection and Ranging
LOD	Levels of Detail (Developments or Definition)

Abbreviation	Definition
LOI	Levels of Information
NEF	Nikon Electronic Format
NURBS	Non-Uniform Rational Basis Spline
PDF	Portable Document Format
RCP/RCS	Reality Capture Scan data
TLS	Terrestrial Laser Scanners
UAV	Unmanned Aerial Vehicle
UNESCO	United Nations Educational, Scientific and Cultural Organization
VR	Virtual Reality
WOS	Web of Science
XREF	External References

1. INTRODUCTION

"Thus, an architect who prepares a restoration project by combining the taste of an artist with the knowledge of a scientist may be able to ensure that the building they intervene in will last longer…" (Gabriel, 1943)

Rationale for the research and problem statement

Humanity makes significant efforts and allocates resources to protect cultural assets (Woodward and Heesom, 2019). Although the tools used to record field data are advanced in documentation studies, which is the technical first step of conservation studies, the data obtained is interpreted with the help of operators and converted into two-dimensional (2D) documentation (Gür, 2017). Solutions are needed for the inefficiency in updating these documents, synchronizing them among stakeholders and data consistency (Arayici, Hamilton, and Gamito, 2006).

The Architecture, Engineering and Construction (AEC) sector has been positively affected by technological developments and undergone radical change (Pocobelli, Boehm, Bryan, Still, and Grau-Bove, 2018). Building Information Modeling (BIM) technologies, which are the actors of change, have been the subject of significant research in the field of historical monument protection in the last ten years under the name Heritage Building Information Modeling (HBIM) (López, Lerones, Llamas, Gómez-García-Bermejo, and Zalama, 2018). However, the software used for HBIM production focuses on new-build production processes (Allegra, Di Paola, Lo Brutto, and Vinci, 2020). For this reason, the issues for which BIM technologies can be useful in the preparation of restoration projects of historical, cultural heritage should be investigated (Arayici *et al.*, 2017).

Research question and hypothesis

Traditional methods are used to design historical artifacts, even in a computer environment. Can BIM be a way out/alternative for the inefficient points in this process? This question attracts researchers' attention and many experimental studies are being conducted. However, testing it in an actual execution project may help to reveal the problems and benefits.

Therefore, the research question is formulated as "to what extent can HBIM be used in restoration projects in professional practice?"

Software used for HBIM studies are designed for new building processes. These software tend to standardize production processes with the help of libraries and minimize errors. However, each detail of the architectural, cultural heritage should be treated as a separate object and modeled with the highest possible level of detail. Therefore, the use of existing BIM technologies and software to produce an HBIM model seems problematic in the first place.

Hypothesis: In order for BIM technologies and approaches to be effective in architectural cultural heritage projects, a new workflow is needed in which existing software can be used for its purposes.

Aim of the research and methodology

The purpose of this research study is to test and evaluate to what extent the restoration projects that need to be done for the protection of historical monuments can be done with BIM approach and technologies.

For this purpose, the restoration project of Mahmud Pasha Hammam in Golubac, Serbia, was used as a case study. The restoration application project was initiated simultaneously with classical methods (AutoCAD) and Autodesk Revit software, one of the BIM tools. The compatibility between the two methods and aspects that support each other were investigated, along with the adequacy of HBIM applications within the framework of today's restoration understanding and expectations.

Research objectives

The usability of BIM software in the proposed workflow was investigated according to the following objectives.

1. To undertake a comprehensive literature review and search to build contextual knowledge about heritage BIM and its cutting-edge practice and implementation.

2. To explore the practicality and usability of Scan to BIM manual data processing for the restoration projects.
3. To experiment with information exchange and data sharing via the HBIM data model with external practitioners, such as structural engineers, involved in the restoration project.
4. To observe the communication capacity and ability of HBIM-based visualization among the stakeholders to establish a shared vision and understanding of the restoration project.
5. To analyze the organizational improvements and accurate cost estimation with HBIM-based procurement practice in the project supply chain.
6. To experiment with HBIM use for conservation and restoration documentation in a collaborative manner for speedy project execution.
7. To evaluate HBIM use in cultural heritage and make recommendations for future research and practitioners.

<u>Research contribution to knowledge and practice</u>

Few of the studies in the field of HBIM have focused on conservation, dealing with a damaged structure without flat surfaces in a practical project. Furthermore, the international status of the Cultural Heritage (CH) chosen in this study required actors from different cultures to work together. Thus, the BIM approach was tried within the scope of a Heritage application project, so evaluations of more than one culture could be compiled. These results provided opportunity for a more objective assessment of the BIM approach within today's expectations.

<u>Thesis structure</u>

The study consists of six chapters. In this first chapter, the problem is revealed, the purpose and objectives of the study are explained, and the findings are briefly mentioned.

The second chapter presents a comprehensive literature review on the importance and methods of documentation within the framework of the concept of cultural heritage protection; classical methods used in documentation and their weaknesses; the general framework for adapting BIM; a new building information management approach to heritage buildings; and current trends and target areas of study in the use of HBIM.

The Third Chapter is about how the research will be conducted and the material chosen. Information about the brief history of Mahmud Pasha Bath, the scope of the work program, the methods and tools used for documentation are given in this section.

In the Fourth Chapter, the works planned to be done within the scope of the Mahmud Pasha Hammam restoration project work program are explained. Restoration outputs have been obtained with classical methods and BIM approaches and technologies.

The Fifth Chapter focuses on evaluating the data obtained in Chapter 4 in the context of objectives 2-6. The findings of the study were discussed over the literature.

In the final section, the extent to which the study results match the purpose, the problems encountered during the study and suggestions for further studies are presented.

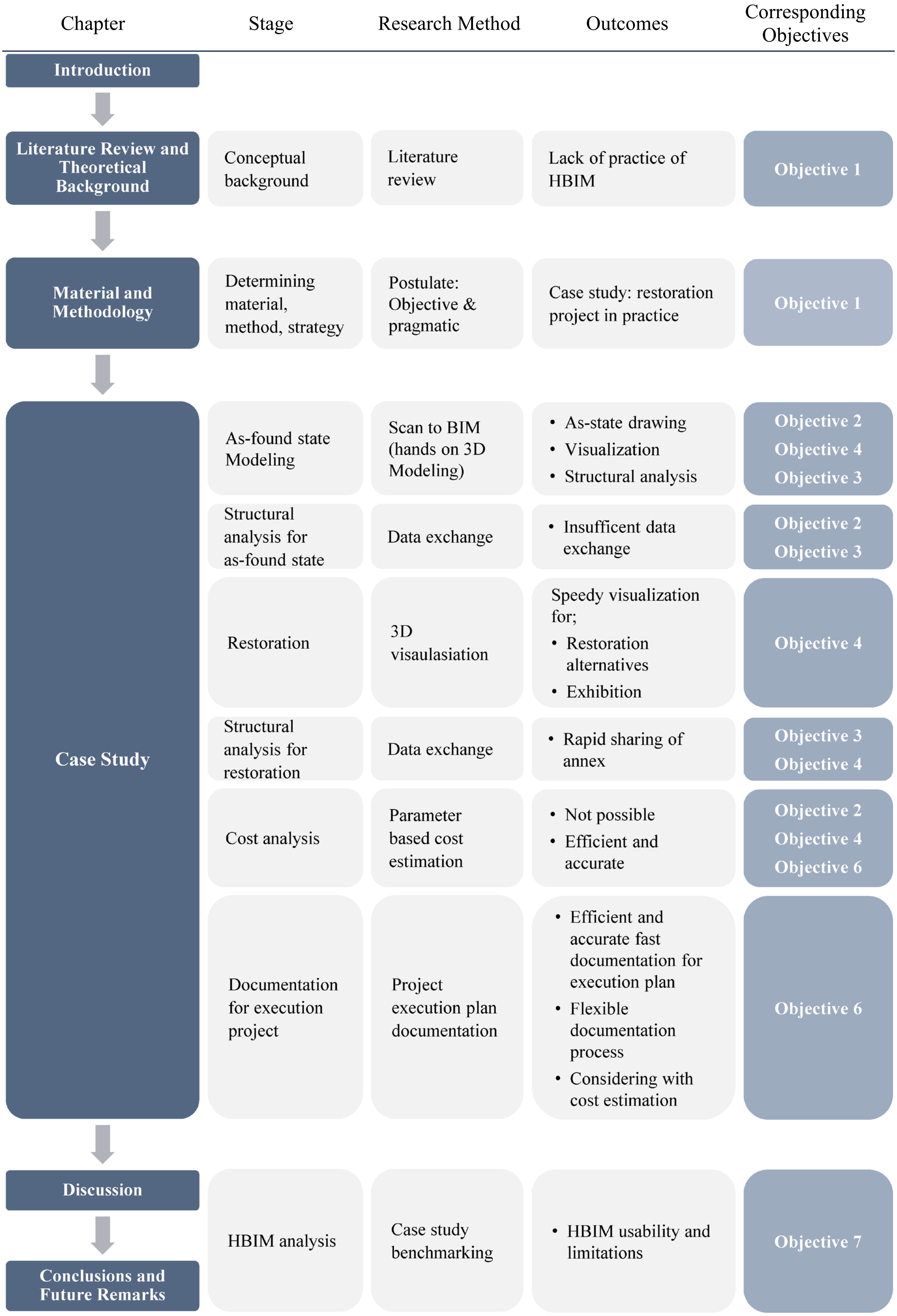

Figure 1.1. Thesis flowchart

2. LITERATURE REVIEW AND THEORETICAL BACKGROUND

This second part presents a literature review within the framework of the concept of cultural heritage conservation and the importance of documentation:

- General concepts, terms, and terminologies
- Conservation process
  - Importance of information sharing, collaboration and actors
  - Typical restoration process
  - Classical methods used in documentation and their weaknesses
- The general framework for applying BIM to heritage buildings
- Identifying trends and target work areas in the use of HBIM

2.1. General Concepts, Terms and Terminologies

"…the process of managing change to a significant place in its setting in ways that will best sustain its heritage values, while recognizing opportunities to reveal or reinforce those values for present and future generations" (Drury and McPherson, 2008).

The desire to preserve old structures has economic and emotional aspects and is an essential element because people and society generally define themselves by their past. But, of course, this was not always the case. If we look away from the intellectual accumulation it has acquired today, restoration is actually a repair activity known to all humanity. In other words, the phenomenon of conservation was a natural lifelong component before the concept of heritage building or environmental protection was developed. In the past, a building's functional value was often a tool and necessity for its continued maintenance and survival. In the same way, demolishing, changing, transforming and collecting parts were considered normal (D. Kuban, 2000). Today, it is exciting to follow this historical accumulation of buildings that have resisted extinction and preserved their originality, read together with the social, cultural and economic facts of the period, and see the evidence on the building.

These works, which affect the human spirit and arouse curiosity with their uniqueness and memories, include the history of humanity. Therefore, regardless of nationality, a cultured person may be interested in these works that tell the history of humanity, first of all, their own history. Therefore, these are not only works of art or historical objects but also documents necessary to satisfy people's sense of belonging (Ülgen, 1943: 5).

The natural and artificial cities, buildings and all the ruins that make up the physical environment carry the message of the cultural environment that created them. But knowing this is not reason enough to protect these products. Sensitivity to the deterioration of the natural and physical environments has developed mainly after the Industrial Revolution. However, especially after the destruction of the Second World War, the atomic bomb, air pollution that made big cities hard to live in and developments that disrupted the biological balance of the world, the concept of protection was added to contemporary concepts such as human rights and democracy (D. Kuban, 2000).

In addition to the values represented by the cultural heritage, it has been accepted as the common heritage of humanity and documented in international conventions (Aydın, 2019). The preamble to the World Heritage Convention states "the degradation or destruction of any part of the cultural and natural heritage constitutes detrimental impoverishment for the heritage of all the nations of the world." It is accepted that "parts of the cultural and natural heritage have an exceptional importance and therefore all humanity must be preserved as a part of the world heritage" and "the entire international community has to participate in the protection of the cultural and natural heritage" (UNESCO, 1972).

Efforts to take a joint stand around the world to protect cultural heritage date to the 1930s. "Carta Del Restauro" can be considered the first document in this field. UNESCO was established in 1945. In 1954, the first international official document, the "protection of cultural values in the event of armed conflict," was signed in the Hague. In 1964, the Venice Convention, which can be described as the first step of institutionalization regarding protection, was announced. Today, many international, national, official or semi-official organizations such as ICOMOS, ICCROM and UNESCO strive to protect cultural heritage (Madran and Tağmat, 2007).

The Venice charter is accepted as the most fundamental international reference document that remains valid in the field of protection. Article 16 of the Declaration states the following about conservation and restoration activities:

> "In all works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs. Every stage of the work of clearing, consolidation, rearrangement, and integration, as well as technical and formal features identified during the course of the work, should be included. This record should be placed in the archives of a public institution and made available to research workers. It is recommended that the report be published" (Venice-Charter, 1964).

It is clear from the statement that heritage information management and documentation activities should be integrated with a conservation management process. The pre-repair status, work done during the restoration and post-repair status of cultural heritage should be documented.

Concepts can have different meanings for different disciplines dealing with conservation. (Bentkowska-Kafel and MacDonald, 2017). At the same time, the meaning of some concepts may have changed. For example, the definition of restoration has changed throughout history. In the past, restoration was perceived as returning an object to a previously known state. This understanding has done great harm and international statements have emerged due to opposing views. Today, as expressed in the Venice Convention, restoration is perceived as preserving the heritage by revealing its originality and cultural value (Feilden and Jokilehto, 1998). With a more technical definition, all the technical and architectural interventions that ensure the prolongation of the life of a building with artistic value as a cultural and historical document, with all its unique qualities, constitute restoration activity (D. Kuban, 2000). Underneath this activity are survey drawings, different types of analysis, historical investigations and restorations, consolidations[1] and conservations (Asatekin, 2004).

[1] Conservation is used for the protection, consolidation or cleaning of building components or movable cultural heritage. It is used here in the second meaning.

In the study compiled from the Heritage Recording, Documentation and Information Management Guidelines for the World Heritage Sites manuscript (Letellier, 2002), which was developed with the participation of ICCROM, ICOMOS and UNESCO in the mid-nineties, documentation, conservation, information management and heritage recording were defined among the concepts.

Conservation, unlike restoration, describes a framework that includes management processes. It aims to protect cultural heritage from adverse effects, such as decay, deterioration and vandalism, and preserve its current condition. Therefore, conservation is directly related to management processes and a multidisciplinary management team should carry out this process within the framework of conservation theory (Feilden and Jokilehto, 1998).

2.2. Conservation Process of Architectural Heritage

“Since physical cultural heritage is one of the most important un-renewable resources in the world, a special effort is needed to address the imbalance between our needs and its protection” (Feilden and Jokilehto, 1998).

Laws and regulations, budgets, experts and managers from many different professional disciplines are needed to record and preserve historical monuments (Gabriel, 1943). Everyone involved in this process should record the process within their field. Thus, documentation, one of the most important stages for conservation, is created collectively. The knowledge gained and documents created should be accessible to anyone interested in preserving cultural heritage. Managers are responsible for taking the necessary measures to ensure information is created, recorded, managed and shared correctly (Letellier, Schmid, and LeBlanc, 2007). As recommended in the Venice charter, a legacy structure must be passed on to the future with all its experience. It is necessary to ensure the continuity of the documentation with the awareness that the records of works done today are proof and document for the future. The purpose of transferring the structures that are considered to constitute the historical environment to future generations is not only to keep them physically alive but also to how they exist in society during their existence (D. Kuban, 2000).

2.2.1. The role of documentation in the decision-making process

Conservation is not only a technical issue but a long-term process with many economic, social and cultural aspects. The sequence of activities that continue throughout the life of the building, including the stages of documenting, monitoring, repairing and using, starting with the determination of the importance of the cultural property and its protection, defines the protection process. Many actors are directly or indirectly involved in this process. Experts who develop conservation policies, politicians who issue laws and allocate resources, authorized institutions that enforce laws and protect cultural heritage, architects, engineers, art historians, users and every individual of society can be counted among these stakeholders. In a process with such a wide range of participants, it is challenging but necessary to collect, understand and evaluate the existing information and the information produced in the conservation process. Documents containing this information must be well-managed to make the right decisions in each aspect of the conservation action. Accurate and fast information is the basis of the decisions taken to protect cultural property. Therefore, the decision-making process is strongly dependent on the accuracy, consistency, and presentation of the documentation.

Actors and stakeholders

To determine the type and scale of the problem, a multidisciplinary team should work together from the first steps of a study (ICOMOS, 2003). Stakeholders directly or indirectly involved in the conservation process make up a reasonably long list (Table 2.1). The areas of expertise needed to protect each cultural property may be different. But mostly, the following actors stand out: administrators, politicians, architects, art historians, heritage recorders, engineers (all sorts), architectural conservators and craftspersons.

The time allocated for recording cultural assets has decreased considerably, thanks to today’s technologies, such as terrestrial laser scanners (TLSs), video cameras or unmanned aerial vehicles (UAVs), that record field data quickly and can effectively hide user errors. However, this stage is considered the most important among the information obtained about a structure. Complete documentation of the problems will ensure the accuracy of the solution proposals and the building’s survival. This why it is crucial to ensure close communication between loggers and conservation professionals.

Table 2.1. Actors that can play a role in the preservation of cultural heritage

administrators	craftspersons	hydrologists
antiquarians	curators	landscape architects
archaeologists	documentalists	legislators
architects	ecologists	mineralogists
architectural conservators	economic historians	museologists
archivists	engineers (all sorts)	petrologists
art historians	entomologists	politicians
biologists	ethnologists	property managers
botanists	geographers	seismologists
building surveyors	geologists	sociologists
chemists	heritage recorders	surveyor
conservators (of collections)	historians	

Conservationists are responsible for interpreting, documenting and sharing data from the field. The project team includes actors with artistic, historical and technical aspects specializing in conservation: architects, art historians, archaeologists, civil engineers, electrical engineers, mechanical engineers, *etc*. The communication of these actors with each other is essential for making correct determinations and taking timely measures. Collective knowledge is heterogeneous, as each stakeholder's needs are for different data types and levels, leading to confusion or difficulties in understanding the information. Although developing technologies have provided new opportunities for information management, this diversity of information may cause losses. The pace of developments in ICT has increased the need for technicians to manage digital information for this group. Increasing sensitivity, developing technologies and increasing expectations on the protection of cultural heritage have increased the amount and diversity of the data produced and necessitated people working on managing information.

A wide range of actors, such as site management, product supply, personnel safety, restoration specialists and restoration workers, are involved in realizing restoration projects. These actors, who are described as field teams, should understand the importance of cultural property and the decisions taken for restoration. Some decisions are taken in line with uncertain information in the project design process. For example, although it is possible to use advanced undamaged fixation methods, some findings during restoration can cause significant changes. To preserve the originality of the cultural property, the field team should read the data, make sense of it and inform other actors when necessary.

Other essential conservation stakeholders are authorized units working to produce policies, allocate budgets and develop a management plan for conservation work. Organizations that control the process include government officials, ministries, local governments, conservation councils/boards, non-governmental organizations and international communities. These formations include politicians, economists, communication experts, architects, historians and engineers.

Another indispensable party that should be included in the protection process according to international conventions is society. Cultural property is the common property of humanity and emphasis is placed on the importance of community participation in conservation processes (Aydın, 2019). In this way, conservation can find a broad base and become a way of life.

2.2.2. Typical restoration process of architectural heritage

"The conservation, consolidation and restoration stages for the protection of architectural heritage can be developed with a multidisciplinary approach" (ICOMOS, 2003).

The international agreements' objectives should be considered a priority and the interventions proposed for the structure should be based on a balanced judiciary. The protection policy involves making interventions at various scales and density levels. These are the physical condition of the cultural heritage, causes of deterioration and state foreseen after repair. Each situation should be carefully considered individually and as a whole, contemplating all variables. Conservation and restoration's ultimate purpose and principles should always be at the forefront (Feilden and Jokilehto, 1998).

In most cases, a conservation and management process for architectural heritage includes the following phases: initiation, assessment, regulation, conservation and management planning, conservation, management, monitoring, maintenance, use and dissemination (Toldo, 2016). The technical process, excluding administrative parts, consists of documentation, research, analysis and interpretation, diagnosis and determination of protection approach, the definition of practical intervention, implementation and monitoring (ICOMOS, 2013).

Restoration requires documentation of the current state of cultural property at the initial stage. The documentation tools are mostly photography and, more recently, the point cloud. These data are converted into 2D drawings by experts. Next, the current state of the building is examined from structural and material perspectives. The identified problems are processed into these drawings by the mapping method. Then, as a result of the examination of the whole life of the work, the phase of determining and evaluating the stages from the beginning of the production process to the present comes. A restitution study is carried out by examining the originality of the current situation and evaluating its historical process. At this stage, the values, problems and possibilities of the cultural property should be examined, and the determination of how much of this life process and for what reasons and scale should be preserved. By evaluating these results within the framework of a scientific conservation theoretical approach, the mainframe of the intervention series is established by determining the protection criteria. It also includes the formation of a physical intervention system that will respond to these criteria, the architectural design required by this system, the evaluation of the cultural property in the context of its relationship and/or contradictions with its environment, determining the most appropriate role it will take in contemporary life, and analyzing these in a holistic manner and reaching a conclusion in which correct information is presented (Asatekin, 2004). All these actions constitute the “restoration” process (Figure 2.1).

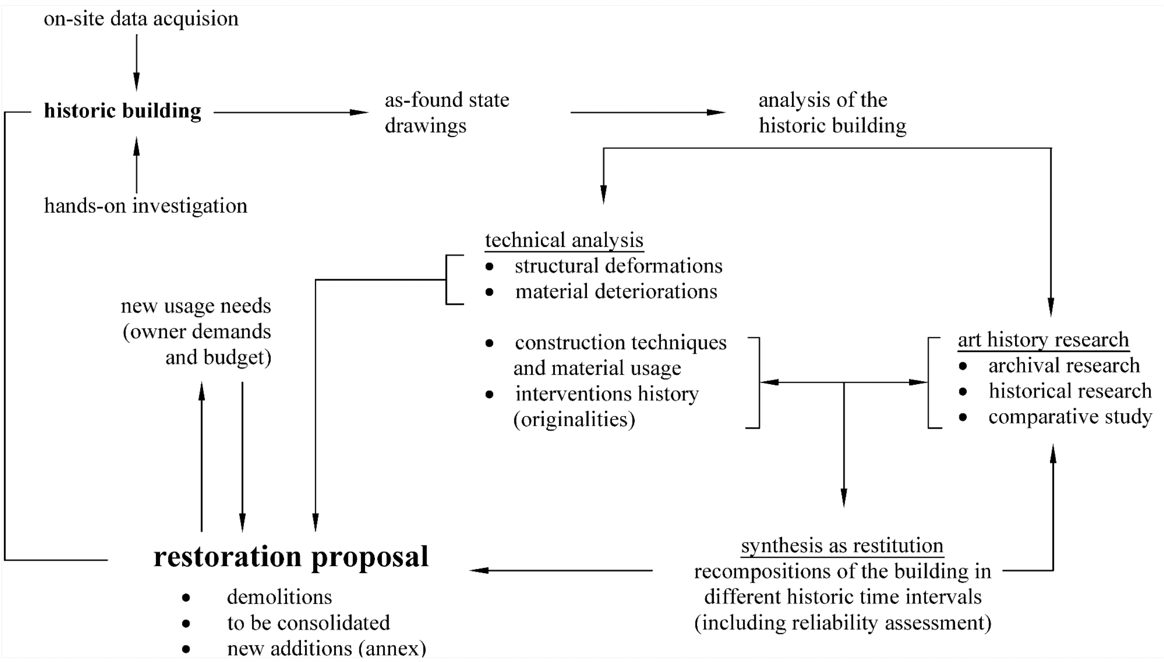

Figure 2.1. Workflow diagram, a typical conservation project

On-site data acquising

Today, thanks to technology advances, the tools used for the measurement of heritage buildings have improved considerably (C. Dore and Murphy, 2017). Photos and videos can be obtained with very high-resolution cameras and hard-to-reach areas can be easily recorded with UAV tools (Karachaliou, Georgiou, Psaltis, and Stylianidis, 2019). Photogrammetry, videogrammetry and a point cloud can be produced from this data (Martinez-Carricondo, Carvajal-Ramirez, Yero-Paneque, and Aguera-Vega, 2020), or point clouds are created with TLSs. Rarely, there are also some cases where classical methods such as laser total station, laser meter and mechanic rulers are used.

The literature shows a lot of work is involved in the acquisition of field data. The most important factor in the value and focus of the subject is the reliability and objectivity of the data produced (Ciribini, Mastrolembo Ventura, and Paneroni, 2015). The principle of authenticity expressed in the Venice Convention coincides with the requirement that the material remains of the heritage be recorded accurately and transparently (Athanasoulis, Simou, and Zirogianni, 2017).

As-found state documentation and analysis

Researching a structure has two aspects and these things are done almost simultaneously. The first of these (as described in Restitution) is the research of the historical data of the building and the second part is the technical research and analysis.

“For diagnosis, observational studies such as material decay, static problems, historical history of the building are required, as well as testable problems and knowledge such as material and structural analysis” (ICOMOS, 2003). Using field data, the building’s current state is documented by creating 2D technical drawings. Generally, it is expected that all surfaces will be shown. The resultant drawings form the basis for all work done after this stage.

Structural assessments are initially made based on observation and experience. Visible damage, such as the load-bearing structure of the building, material quality, foundation and ground condition, and any interventions are detected and photographed, and the building’s current state is documented. As a result of the observation and preliminary examination report, it can be decided whether further determination studies are necessary. If deemed necessary, a simplified numerical model representing the current situation is prepared, the building system behavior is calculated and the benefits for its strengthening are taken (Kaptan, 2010). This stage is important for the survival of the building and user safety. The problems identified here will be evaluated during the restoration phase and will be the basis for solution proposals.

To examine, determine and deal with the damage and deterioration architecturally, it is necessary to know the building's general information, construction system and data on how the details are resolved at the element, component or material level. In addition, knowing and analyzing the building's conditions also affects determinations regarding the occurrence and elimination of damage. Various information is obtained from studies prepared on the damage and deterioration in existing structures. Thus, the approaches and methods developed by experts working on structural damage can be understood (Gür, 2017).

After obtaining physical data about the building, analyses should be made. First, the building's problems are determined and marked on the drawings with the mapping method. The issues can be examined under several headings (Madran and Özgönül, 2005: 39):

- Structural issues
- Material issues
- Environmental factors
- Legal issues
- Human-related problems

In addition, evaluations should be made regarding the source of the problems. Thus, the seeds of the issues can be identified and permanent solutions can be produced by reaching the head of the problem rather than eliminating the symptoms (Ahunbay, 2009: 38).

Samples are taken from the building materials and analyzed, to obtain the physical data of the material used in the building and to use it in the restoration phase and understand the periods of the building while the restitution is being prepared. These assays can be used for specificity analyses. Comparisons are made with similar structures to analyze the current state of the building on a periodical/historical basis, and in cases where there is doubt about the period, samples can be taken from tissues that are known to be original and evaluated in suspicious condition. After this the visual, written and verbal sources related to the building are searched, the repairs it has undergone and annexes it has taken are separated. While preparing the originality analysis, the original parts of the building, qualified period annexes and unqualified annexes taken in certain periods are specified.

Restitution

Various data about the building should be collected, such as photographs, videos, narratives, newspaper reports, travelers' narratives, engravings, old expenditures and commission archives. These data can be obtained from many sources such as personal collections, government archives, films, newspaper archives and historical books. Although it is a laborious process, it is the most important step that gives the restoration its real shape and gives meaning to the repair. It is aimed at preserving originality in the restoration works.

Restitution proposals are prepared by evaluating the originality analyses made at the survey stage and historical data. Many changes may have been made from the time the building was built to the present day. All these changes tell the building's historical adventure. Reports and drawings are prepared for each period. This study should be considered not only as a basis for restoration decisions but also as important information to pass on to future generations (Letellier *et al.*, 2007).

Restoration

In the archive documents collected about the building, intangible information, such as the history of the region, user information, physical condition and owner's demands for new usage, are brought together and intervention decisions are taken with the awareness of the responsibility and the fact the building is the society's property. During the restoration phase, three critical decisions are made: partitions to be removed, to be preserved and new additions.

A demolition project requires restitution. The most basic evaluation method for deciding what to remove is restitution. The building's current state can be evaluated in the light of historical documents and the decision to remove the non-precious can be taken. These decisions are recorded on the survey drawings.

The structure's problems are determined with the analytical survey. After the removed parts, the original parts of the remaining structure should be strengthened and its problems should be eliminated. This stage is called consolidation. At this stage, no new additions are made, but repairs such as reductions in masonry, plaster repairs, joint repairs and stone replacement, which have a static effect, are made. Large-scale reinforcements (additional wall, steel, *etc*.) required to ensure the building's survival, completions suggested with strong evidence in restitution or additions needed in a case for re-function are shown at this stage.

Static calculations must also be made for all three phases to be prepared under the roof of restoration. For example, add-ons that need to be removed from the structure have started to take loads over time and situations where removing them are risky are frequently observed. The analyses to be made during the consolidation phase determine how much reinforcement the structure needs. In cases where reinforcement with massive additions is required, the architectural team has the responsibility to find aesthetic solutions for retrofitting as well as functional additions.

2.2.3. Architectural heritage documentation: Needs and challenges

Recording and documenting immovable cultural property are the basic elements of conservation practice. In the process of preserving cultural property, new information always emerges and this needs to be evaluated by experts. In such cases, new decisions are taken to change the implementation method and new documents are created due to these decisions. Understandably, this knowledge tends to increase as the preservation process continues. Therefore, archiving and sharing the information constantly produced and consumed by conservation stakeholders is one of the most important elements in terms of conservation. The diversity of the data source is the compelling factor here. Although there are many social, legal, economic, cultural and technical aspects of preserving cultural property (Letellier *et al.*, 2007), there are two main aspects in terms of documentation. One of them, as a source of information, is the buildings and their history, context, evolution over time, *etc.*; the other is the physical data available to provide a comprehensive description (Toldo, 2016). Conservation planning and implementation should be based on and managed by these two types of knowledge. In terms of protection, correct information management can be defined as the processing of information obtained from one or more different sources in a way that optimizes the access or access of everyone with this right (Letellier *et al.*, 2007).

Traditionally, cultural heritage documentation is a combination of graphic and written records, and the form of information management is archiving printed materials such as drawings, documents and photographs. With the development of ICT, it has become possible to manage the ever-increasing data flow more effectively. Although there are recommendation texts from many international organizations such as GETTY, ICCROM, ICOMOS and CIPR on what information should be included in the studies for the certification of CH, there is no standard for technical content. Management of knowledge has become a growing problem due to the increase in the knowledge available in the field and the ever-increasing level of knowledge demanded by authorities (Hill, 2005). Information management can become even more complex by adding information from different disciplines such as historical research and documents, legal procedures and cost elements to field data. If an information pool that grows over time is managed correctly, the success rate in protection processes can increase and resource savings can be achieved. Toldo (2016) argues the best data visualization should be prepared in such a way that no additional information is needed in the decision-making process. However, although detailed field data can be obtained with tools such as 3D laser scanners, video cameras and panoramic photographs, collected data that is processed and reduced to 2D can be seen as a limitation of data visualization. The fact the documents obtained during the determination of the current situation, demonstration of the problems, restitution and restoration stages are technical prolongs the actors' understanding process. Stakeholders request or provide data of different types and levels of detail in the decision-making process. Due to the differences in each stakeholder's professional background, they should not be expected to clearly understand the technical drawings. Cultural heritage is the common property of all humanity. For the health of conservation, policies should be developed so this concept can be adopted by society and turned into a way of life. However, documentation processes mostly focus on implementation projects. The fact the documents produced in terms of individuals who contribute to the protection process are very technical can be perceived as an obstacle to participation. Documents such as plans, section views and system details should not be expected to be read and understood by every participant.

Using CAD in CH restoration projects offers a proven workflow. Each line drawn for the expression of the structure can be with the precision of an artist. It is possible to combine technique and art. These systems generally do not have software compatibility problems. The generated data is small in data size, easy to distribute and effortless to convert. Hardware power requirements are relatively low. Although it seems advantageous, with the development of ICT, the data collected from the field is high and considerably reduced by hand in these systems. While the point cloud can show the structure in 3D, the plan is converted into 2D technical drawings such as a section view; the data is reduced. Despite all these technological developments, it is possible to say the end-product of these kinds of documentation is only 2D drawings and reports. In other words, although the quality of the data obtained from the field has improved, classical (2D documentation) methods are still used in the design of historical monuments. This reduction process takes quite a long time. The process may vary for different heritage buildings. Although CAD is flexible, there is a need to create different workflows according to the building's requirement.

Another significant issue is data consistency. Documents produced with CAD systems are obtained with the help of operators. The work of more than one expert on a project causes difficulties in ensuring data consistency. In addition, it is necessary to analyze the overlap of the works of different disciplines such as architecture and electrical mechanics. Any change requires making changes in architectural sheets and many documents, such as static or mechanical. The resulting documents must be re-registered and certified. This process is very repetitive and tiring.

2.3. Building Information Modeling (BIM)

Developing digital technologies cause radical changes in architectural discipline as in every field. BIM technologies, which have entered the area following the developments in CAD and CAM, have also been the harbinger of a paradigmal change by providing the opportunity to digitally coordinate the highly complex construction process before the structure is physically produced (Khosrowshahi and Arayici, 2012).

The core hypothesis of BIM is collaboration by different stakeholders at each stage of a facility's lifecycle to add, extract, update or modify information in BIM to support and express that stakeholder's role. BIM is a database that includes geometric and non-geometric information and is usually represented on a digital 3D model (Abd and Khamees, 2017). Stakeholders upload and receive data at different detail levels from this database according to their needs and purposes.

BIM technologies are seen as a mechanism that promises productivity, efficiency, pre-production error detection, rapid visualization, shortening design processes and data consistency in the construction industry (Arayici, 2015). But it can also be used as a digital twin of a structure (Jouan and Hallot, 2019, 2020), a platform for experts from different disciplines to collaborate (Simeone, Cursi, Toldo, and Carrara, 2014), an advanced tool for managing an asset set (Antonopoulou and Bryan, 2017; Baik, Yaagoubi, and Boehm, 2015) and a platform for educational practice (Atkinson, Campbell-Bell, and Lobb, 2019; N. Kuban and Kahya, 2016) .

2.3.1. BIM for the built environment

Preserving and strengthening the existing building stock for economic and cultural reasons is gaining importance and plays a vital role in improving quality of life. Sustainable growth causes an increase in demand in the sector, especially in developing economies (Ahuja, Sawhney, and Arif, 2018). Over time, it has gained a place not only in construction processes, but also in many areas such as facility management, risk analysis, asset and waste management, regardless of existing or new structure (Volk, Stengel, and Schultmann, 2014).

This wide usage area of BIM is valid for heritage buildings, but it can also offer more. Today's BIM technologies are mostly focused on design and manufacturing.

2.3.2. An overview of HBIM

The idea of BIM was developed by Prof. Dr. Charles Eastman as a 3D system in which documents produced for building design are linked (Scianna, Gaglio, and La Guardia, 2020). But its inspiration is Computer Integrated Construction. Computer Integrated Manufacturing was the first proposed concept instead of BIM. Worthing and Counsell (1999) designed a database model for the London Tower in 1996. However, the first significant adaptation is considered a virtual reconstruction of the UNESCO site Lascaux Caves in 1995 (Arayici *et al.*, 2017).

It can be said the HBIM concept began to emerge in the mid-1990s with legacy projects using scanning technologies along with 3D models (Al-Muqdadi, 2020). However, Murphy gave the literature the name HBIM. He took advantage of the lack of a modeling library for cultural heritage and proposed a parametric library in .GDL. Talking about the difficulty of modeling due to the lack of a library for heritage buildings in the first place, Murphy conducted a library study for historical artifacts such as the library used while modeling new structures. In this respect, it can be said that HBIM's debut was only in modeling.

In the following two decades, many research projects used different approaches, such as Geographic Information System (GIS), to document heritage sites and contributed to the spread of digitalization. UNESCO drew attention to the HBIM concept at the conference "Memory of the World in the Digital Age: Digitization and Conservation" in 2012, further strengthening the argument that HBIM can be used for cultural heritage (Al-Muqdadi, 2020).

As studies on HBIM increased, the usage area of the model expanded and the concept of Built Heritage Information Modeling and Management (BHIMM) emerged in Italy in 2014. BHIMM (Ciribini *et al.*, 2015) has parallel content with the building lifecycle. Unlike the first concept, it is conceptualized that asset management can be done through the model.

2.3.3. Current implementations of BIM for architectural heritage

“For the preservation and restoration of monuments, all science and techniques should be used to assist in studying and conserving the architectural heritage” (Venice-Charter, 1964).

The primary purpose/motivation of HBIM studies is to automatically generate the technical drawings and charts required for the restoration of the building from a 3D model from numerical data (point cloud, photograph, video) showing the current state of the heritage building (Murphy, McGovern, and Pavia, 2013). Over time, this purpose has evolved to become a platform for more information production and sharing. This differentiation in perspective increases interdisciplinary cooperation and provides new opportunities. With the HBIM approach, a continuously updated digital recording platform can be obtained to use throughout the structure’s life for the asset information of the CH (Woodward and Heesom, 2019).

Transferring the obtained model to different platforms opens many possibilities. Asset management is possible by integrating buildings with city-scale management systems (Wang, Pan, and Luo, 2019). Knowing the structures that will require urgent intervention in times of disaster (Jiao *et al.*, 2019) is essential for transferring our cultural building stock to future generations. The resulting model can be transferred to systems such as VR and used for education or cultural tourism (Bonenberger, 2019). The fundamental changes that the building has undergone can be transferred to web-based systems and opened for the public’s benefit (Saygı, 2016). Publication of the model can facilitate data sharing between workgroups. It provides the opportunity to make many analyses, such as energy efficiency analyses (Nagy and Ashraf, 2021), lighting calculations and structural analyses (Pepe, Costantino, and Garofalo, 2020).

The most striking subject in the field of HBIM is modeling studies. Although the purpose differs, the priority is to obtain a reliable model (Banfi, 2017). It aims to produce the BIM model using the point cloud obtained from the field via TLS, LIDAR or photogrammetry. This process, often called Scan-to-BIM, focuses on manually obtaining models (Woodward and Heesom, 2019). Due to the complex nature of the heritage building, the modeling process is laborious and the size of the effort is attributed to the lack of parametric libraries. A platform is created where a large amount of information can be associated with each object in BIM libraries having predefined relations with each other. Thus, meaningful objects represent architectural and structural elements. Using predefined objects makes it possible to determine different variables such as material and size without the need for remodeling (Banfi, 2017).

The BIM approach allows automatic repetitive work in operations to save labor and time. However, the time and effort demanded by modeling are considered a problem. As a solution to this problem, automatic object detection technologies are being studied (Croce *et al.*, 2021; Tang, Huber, Akinci, Lipman, and Lytle, 2010). However, automating the process does not represent the distortions and irregularities that should be documented in the historic structure. In addition, at this point, flat surfaces and simple geometric shapes can be recognized (Di Stefano, Malinverni, Pierdicca, Fangi, and Ejupi, 2019). Therefore, mostly manual modeling is more efficient (Scianna *et al.*, 2020).

There are also different approaches to the hands-on modeling process. Parametric BIM libraries can reduce repetitive modeling work. However, the ability of these libraries to represent CH is questioned. The reasoned explanation is the acknowledgment that every building is unique. In this case, the effort to make the libraries parametric may be unnecessary. Instead, objects can be modeled with the solid model approach (Scianna *et al.*, 2020). The tools offered by BIM software often do not provide enough flexibility, ease or precision. This may not be a shortcoming because the purposes for which it was designed are already built on standardization. It has been suggested in many studies to use different software together for this problem and to import mathematical surfaces such as NURB into the BIM environment. However, these models cannot be parametrized in the BIM environment However, the parameterization of an architectural heritage element is not always useful. The standardization brought by parameterization is often not helpful because it cannot represent the diversity of architectural details or the presence of deterioration due to construction techniques (Scianna *et al.*, 2020).

Of course, it is important what the model is built for because the sensitivity and modeling stages change according to the purpose. For example, mathematical modeling methods can visualize a CH heritage for education or tourism purposes and create virtual tours (Napolitano, Scherer, and Glisic, 2018; Nocerino, Menna, Farella, and Remondino, 2019).

In this case, the precision of the model may not be essential. However, the level of knowledge in the model and its sensitivity in representing the asset are important in the studies carried out to preserve historical artifacts. In many studies examining these issues (Brumana *et al.*, 2018; Liu *et al.*, 2019), the correlation between the purpose of the model and level of detail has been emphasized within the framework of concepts such as Level of Detail or Development (LoD), Level of Information (LoI). However, there is no standard in this regard. Different classifications such as GOG and GoA have also been studied (Banfi, Brumana, and Stanga, 2019; Brumana *et al.*, 2018).

Although the model's purpose is a criterion for determining the level of detail, this is not the case for the cultural heritage protection process. A CH legacy should contain as much detail as possible, like the LOD500 GOG10. Thus, a digital representation of cultural heritage "as-found" can be obtained (Bruno, De Fino, and Fatiguso, 2018). The highest level of detail is necessary for the accuracy of interventions. Still, it should not be forgotten that the digital copy of the structure is a document for future generations (Letellier *et al.*, 2007).

The fact the model produced for conservation and restoration is at the highest level of detail causes contradictions in some cases. For example, to perform static analyses of a CH heritage, the structure should be simplified, while the representation model of the cultural heritage is expected to have the most detail. While small cracks observed in a structure are a requirement for the architectural model, it is a problem for the static model. Establishing the balance in the HBIM approach, which claims to be a platform for collaborative work, is a significant problem (Adami, Scala, and Spezzoni, 2017).

However, for some data-sharing scenarios, the level of detail may not be necessary. For example, when BIM-GIS integration is made for systems such as asset management, the model's sensitivity does not matter. But there are problems with data transformation in this area. Although the IFC format is promising for connecting the HBIM model and CityGML (C. Dore, Murphy, M., 2012), data transfer is difficult due to the fundamental differences between both file systems. In addition, the LODs do not correspond between the architectural and city models. When it comes to BIM-GIS or HBIM-GIS integration, the building's relationship with its environment is usually examined. Shadow analysis is used to analyze damage caused by natural disasters such as floods and landslides, reduce energy consumption or establish emergency response networks. It manages the GIS environment for planning and building, technical-economic assessments, virtual reconstruction and asset management (Colucci, De Ruvo, Lingua, Matrone, and Rizzo, 2020).

It can be said that HBIM stages are shaped according to the goals and conditions of each project (Al-Muqdadi, 2020). But it lacks the flexibility needed due to the unique nature of heritage buildings. For example, devastated areas may not offer physical features to scan and therefore may not be in the research phase, only modeling based on historical documents. Other projects may require specific uses such as analysis, structural or thermal analysis, or visualization that will require the addition of a fourth phase that includes the use of purpose-built HBIM.

2.3.4. Research trends on HBIM

Using BIM technologies to preserve heritage buildings is still a new concept. However, there are significant differences between processes for new building production and the preservation of cultural assets. Several questions were asked to create contextual information about adaptating HBIM studies and identifying a correct research topic: What opportunities do BIM applications that change the AEC world offer for CH? What work is being done in this area? What are the studies' limits and target study areas? What tools were used and structures were chosen as fieldwork? Thus, it was possible to see the all stakeholders' working areas and the direction of trends in the context of HBIM.

The BIM concept has been involved in the building industry at many levels. BIM can be seen from a narrow or broader perspective (Volk *et al.*, 2014), as modeling or Life Cycle (LC). As a result of the orientations and findings of BIM adaptation studies, literature research was carried out from a wide perspective to determine the targeted study areas. To achieve the appropriate papers, a script was facilitated to search the WOS catalog:

Ti or AK or KP=
(hbim or h-bim or BHIMM) or ((heritage or historic* or (existing buil*) or as-built or (built heritage)) and (BIM or (inform* and (buil* or model*)) or (virtua* reconst*))))

The "document type" was set to "article" or "review." Other types (conference papers, books or book chapters, short surveys, *etc*.) were omitted as they would complicate the analysis process and not contribute to the results. From this search, 267 papers have been obtained. After a quick skim and scan, irrelevant papers were excluded. The 71 most cited papers have been evaluated in detail and clustered. To identify research areas and gaps in the literature, research questions, methods and target areas of the articles were determined and labeled. The articles are examined under several headings:

1. Purpose/objectives of the research
   - Conservation Process (Restoration, Reconstruction, Restitution, Refurbishment)
   - Cultural Dissemination (social issues, education, tourism, …)
   - CH Management (urban scale, little object included and except 1.)
   - Tool or Workflow Improvement (technical issues, new approach to contribute HBIM,)
   - Other (literature review, various types of Analysis, Facility Management)
2. Methodology proposed to achieve these goals
   - Data Capturing and Processing (laser scanner, UAV, generating point cloud, photogrammetry, videogrammetry, …)
   - Object Recognition (AI, parametric modelling)
   - Model(ing), Implementation (by human effort)
   - Data Management (database creation, semantic web, ontology, …)
   - Analysis (material, structural, energy, risk, monitoring, …)
   - Augmented Reality (VR)
   - GIS-BIM Integration
   - Review (literature, criticism, state of art)
3. Field of study described as the result of the research (gap)
   - Classification Issues
   - Collected Information Sharing
   - Damage Recognition
   - GIS-BIM integration Issues
   - HBIM Understandings
   - Heavy Model Issues
   - Level of Information Issues
   - Modeling Improvement
   - No Gap Reported
   - Object Recognition Issues
   - Point Cloud Handling
   - Precision or Accuracy of Model
   - Qualified Employment
   - Tool Qualification Problem

- Uncertain Data Handling
- Update Information
- Visualization Techniques

4. Tools/software used in the research
5. Structure types modeled in the implementation

- Complex Structure
- Constuction Site
- Damaged Structure
- Heritage Site
- Literature
- Masonry
- Mural Painting
- Narrow Site
- Nature
- None
- Planar Surfaces
- Steel Structures
- Urban Scale
- Wooden Structure

Thus, connections can be seen between the method chosen for this study, tools used and new study areas described in the results obtained.

All the articles were read and keywords determined in the question fields given above were entered using an Endnote database, exported in CSV format, processed with an Excel power query and converted into graphics via sankeymatic.com.

2.3.5. Literature evaluation over findings

Three graphics were prepared for the studies examined under five main headings. Figure 2.2 examines the aims of the studies and the problems encountered by years. Figure 2.3 examines the study's purpose, method used and problems encountered. Finally, Figure 2.4 shows the case study type, gap and tools used in the study.

Multiple tools and methods can be used in a study and identify multiple research areas by reporting problems. This should be considered when reading the graphics.

HBIM adaptive's main purpose is preservation of architectural cultural heritage. But, as a method, it depends on technology and the most studied area of the reviewed literature is tool development. In addition, people working in the conservation discipline and experts from the field of ICT work in this field make improvements (Balado, Diaz-Vilarino, Arias, and Soilan, 2017) on the reported needs. Therefore, this should be considered a normal situation. Since the emergence of the HBIM concept, interest in tool development has increased and takes the largest share in each year (Figure 2.2 and Figure 2.3).

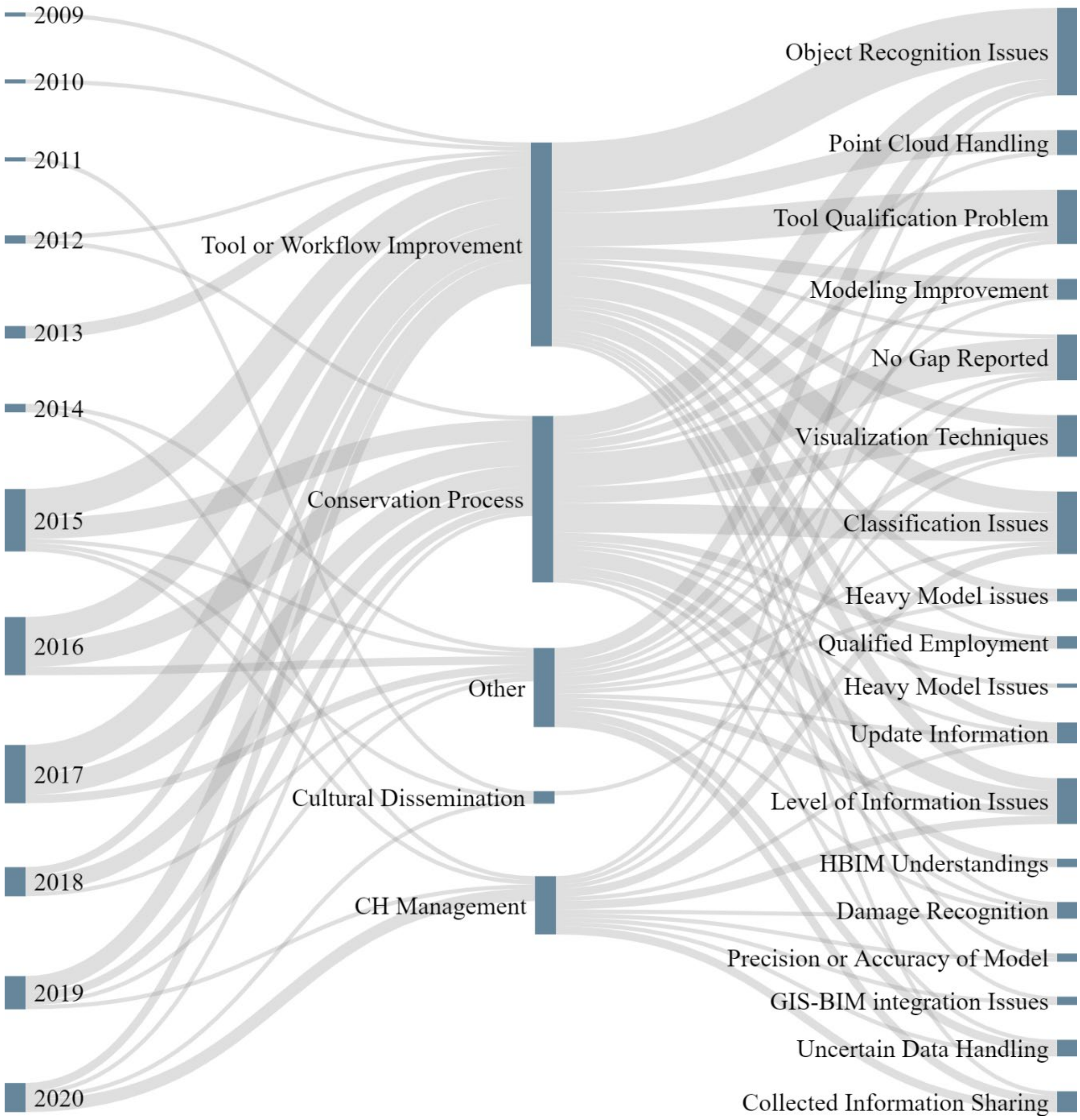

Figure 2.2. Year – Purpose/objectives of the research – GAP graphic

The most basic step is obtaining the model. However, the biggest problem in studies aimed at tool development is object recognition (Banfi *et al.*, 2019). HBIM production is very laborious and time-consuming, which necessitates automatic model generation from a point cloud.

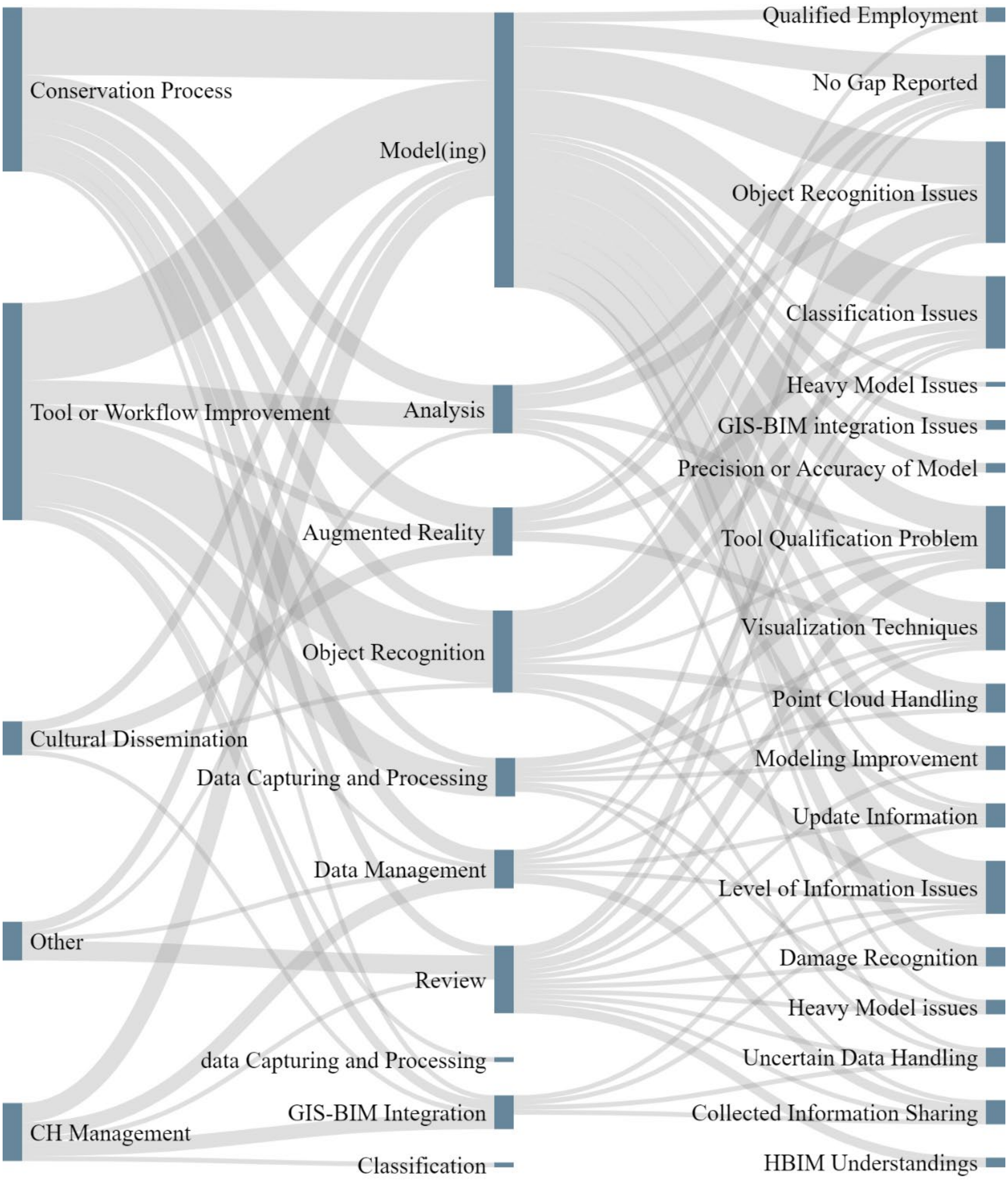

Figure 2.3. Purpose/objectives of the research – Methodology – GAP relation

The scarcity of data capturing and processing work may be due to the technologies in the market reaching satisfactory levels. The studies focus on tools and modeling rather than results. This situation could be attributed to the inadequacy of modeling tools. Among the problems mentioned in the studies, this view can be confirmed through model-oriented problems such as tool qualification issues, modeling improvement, object recognition issues, precision or accuracy of model.

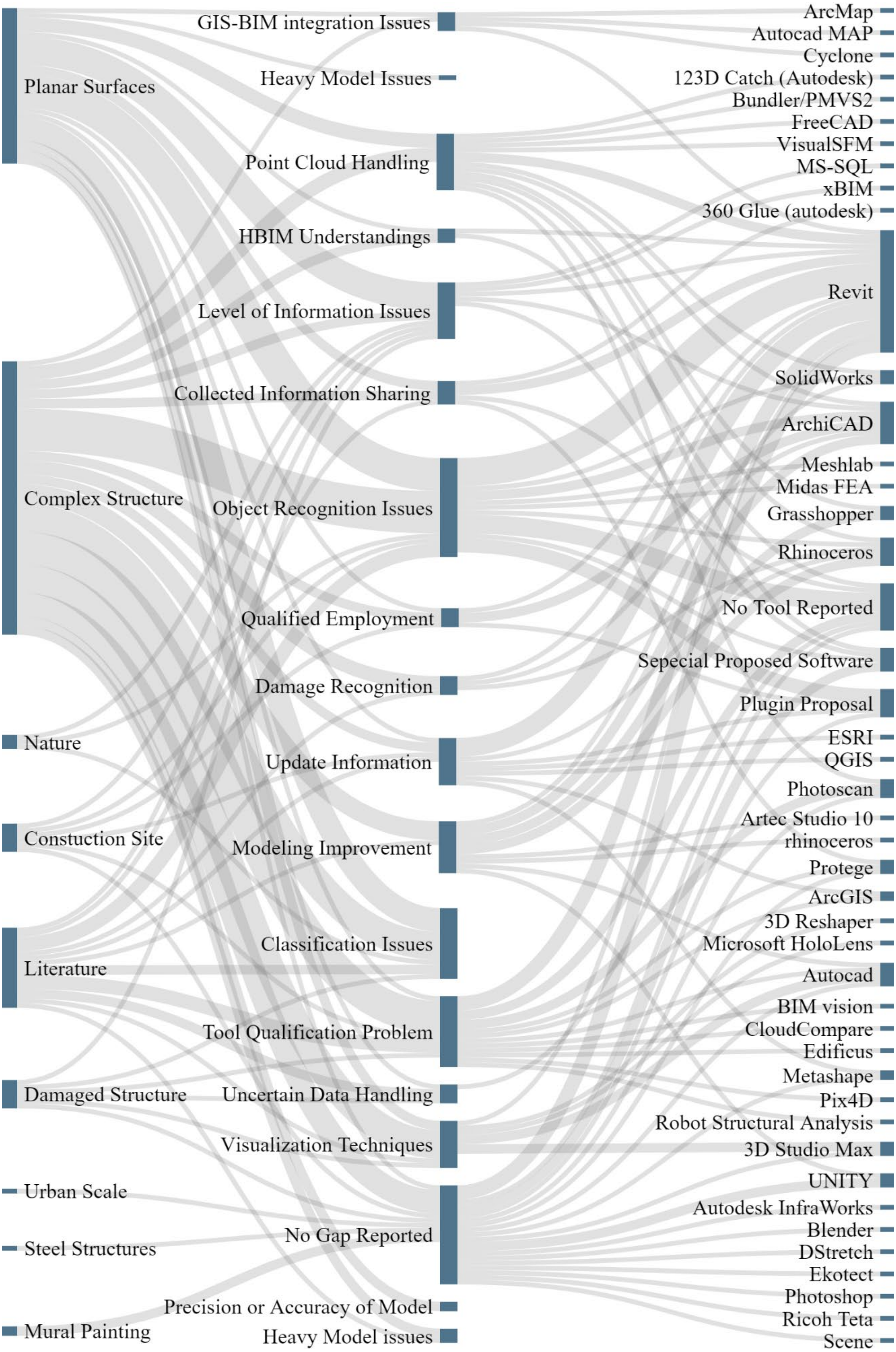

Figure 2.4. Case type – GAP – Tool relation

The major problems include classification, LOI and uncertain data handling (Cheng, Yang, and Yen, 2015). The challenging factors include a lack of specialized software for HBIM generation and absence of specific areas where the historical structures' character can be documented during modeling (Soler, Melero, and Luzón, 2017). The existence of various modeling methods for the historical structure's unique objects can jeopardize data integrity. The result of these negative situations is data loss in data sharing (Biccari, Malagnino, Corallo, and Zavarise, 2017).

Structures produced with newer technologies, which are clearly distinguished from classical construction technologies, especially with elements such as floors, columns, beams and roofs, are classified as "planar surface". Most of these studies aim to automatically extract objects from point cloud (Macher, Landes, and Grussenmeyer, 2017). The "complex structure", which has the largest share in the graphic, refers to buildings such as arches, domes and vaults, which were manufactured using classical period building technology. However, most studies that suggest workflow/BIM implementation choose structures in good condition. Very few studies have investigated damaged/ruined structures. One important stage in restoration work is to detect structural damage and it is vital for BIM software to document/model structural/material problems. This may negatively effect the evaluation of the selected workflow and software capabilities.

Among the studies examined, the common problems mentioned are difficulty of modeling, inadequacy of modeling tools and limited classification of obtained data. In addition, although non-destructive methods can be used to determine the current situation in heritage buildings, determining a method to manage uncertain data is mentioned as a significant problem (Khaddaj and Srour, 2016).

2.3.6. Conclusion: Needs and challenges

The introduction to almost all studies shows HBIM as the target study area, saying traditional methods take a lot of time and are not effective. The findings of the same studies also complain that HBIM is inadequate, especially in terms of modeling tools and standards; therefore, an HBIM trial consumes a lot of time and resources.

In most studies, Revit software is used to model buildings with old construction technologies and some negative situations are explained; 15% of the studies did not indicate any problems.

The concept of “conservation” is not revealed even in studies that take this concept as their subject. In the context of HBIM, few studies focus on cultural heritage conservation. Therefore, it is not easy to evaluate whether the results of the studies are successful. Although the success criteria are consistent with the study’s purpose, its usability within the framework drawn by the protection concept is not discussed (Woodward and Heesom, 2019).

Although the model was created for different purposes (GIS, structural analysis, energy analysis, cultural dissemination, FM) and business disciplines (architect, archeologist, civil engineer), the resulting information should be shared between other fields. This is one of the fundamental arguments of BIM. However, it is difficult to share historical artifact models, mainly due to problems with classifying objects, as explained in the previous heading. Information will likely be lost when transferring a non-standard object to another format.

In studies, one mostly encounters model acquisition attempts. Today, few studies question BIM tools’ adequacy in historical artifacts projects and focus on professional usability. These studies emphasize the need to test the HBIM process in an application project. In addition, the example building types from the studies, flat-surface structures were mainly were chosen to develop tools that can make automatic models in adaptation studies (Zeibak-Shini, Sacks, Ma, and Filin, 2016), while solid and usable structures are used in the trials of structures containing historical elements. However, this situation is not entirely true. Except for the archaeological field studies of (Olson, Placchetti, Quartermaine, and Killebrew, 2013; Rua and Alvito, 2011), only good condition structures are modeled. Unfortunately, important cultural assets are underground, excavated, dilapidated or problematic structures. Selecting a ruined structure for HBIM will provide more data on competence.

3. MATERIAL AND METHODOLOGY

As a result of the literature research on the subject, it has been concluded that BIM software is not made to produce HBIM models; its use is to protect and manage the cultural heritage is promising, but it should be tested in practice. Therefore, this section describes the process of demonstrating the usability of BIM software in a real case study; that is, in a historical monument project with limited time and contractual responsibilities.

3.1. Research Philosophy

The effort to preserve cultural heritage is multidisciplinary. Many stakeholders produce information of different types and complexity. The management of the data produced has a significant impact on the success of the protection. Today, classical methods of information production limit data sharing and decision processes can be damaged because the data flow is disrupted.

In the literature, HBIM implementations are presented to share information while keeping it dynamic. The basis of the studies carried out under the title of HBIM is the creation of a qualified and detailed model. According to the research results in the literature, it is possible to produce models for many different purposes. A model must be created and shared for whatever purpose it is used. The model's sensitivity for different purposes is scalable, but its precision and sharpness to achieve conservation projects seem to be the biggest obstacle ahead. The extent to which the model can represent the structure and quality of the documents produced automatically from the model is vital for HBIM applications to have a place in practical life because project management and archive still demand static information, *i.e.*, 2D documents. The employer determines how the produced projects will be delivered, shared and archived.

Economic returns are the reason why BIM dominates change in the AEC sector. The primary purpose is to spend resources wisely and ensure a fast return on investment. In practice, increasing HBIM application examples in practice can be beneficial to persuade employers and thus increase demand. Discussing how BIM can be used and its contributions in conservation-implementation projects prepared for a destroyed structure under a contract with no BIM expectation can contribute to the dissemination and development of HBIM.

In terms of the starting point, the problem's existence has been reached by evaluating the literature. While the ontological position is objective, acceptance can be described as the data produced is statically managed and shared. In a pragmatic manner, it is suggested to "try" to evaluate the proposed HBIM technologies for keeping data dynamic. This theory has also been used to assess the findings. Besides the classical method, HBIM's level of use has been investigated and the points where it can be useful have been tried to be determined.

3.2. Research Strategy: Case Study Research

In this section, for a workflow in which BIM technologies can be used following their design purposes – selected structure, definition of the job and tools chosen for this job – are explained.

3.2.1. Mahmud Pasha Hammam

To investigate the contribution of HBIM adaptations to the restoration project execution workflow in practice and produce new BIM usage scenarios, Mahmud Pasha Bath, an early Ottoman period bath structure in the Golubac region of Serbia, was chosen as the field study.

Mahmud Pasha Hammam is located in the northeast of Golubac city and on the southwest side of the historical castle. The building, on the edge of the Danube, is now in ruins (Figure 3.1). The artifact, which was partially underground until recently, was completely exposed and taken under protection in 2014 with archaeological excavations carried out by the Serbia-Belgrade Cultural Monuments Preservation Institute.

Figure 3.1. Location of Mahmud Pasha Hammam, Google Earth, 27 April 2019: 11.45; Milenković, 2019 (lower right)

There is no definite information about the date on which the work, which does not have an inscription or foundation certificate, was made. From the sources and documents, it is understood the bath was built by Mahmud Pasha, who conquered Golubac Castle and the city in 1458. The famous traveler Evliyâ Çelebi, who came to visit the city in 1664, tells the following in his travel book: the castle was conquered by Martyr Koca Mahmud Pasha and a Hammam that belongs to him was here. In the writings of Felix Kanitz, an Austrian-Hungarian researcher, ethnographer, painter and traveler, who visited the city in 1859, it is stated the bath lost its functionality in the middle of the 19th century and was partially in ruins (Figure 3.2).

In the second half of the 20th century, it is seen the bath was used by a private company called PIM for the storage of explosives and several parts of the building (destroyed and worn parts) were reinforced with concrete material in this period (Milenković, 2019). The structure, largely buried until recently, was completely exposed and taken under protection during the archaeological excavations carried out by the Serbia-Belgrade Cultural Monuments Preservation Institute to revitalize the Golubac Fortress (Figure 3.3).

Figure 3.2. Golubac, Mahmud P. (Angelovic) Hamam, now below surface [XXIII-c12162-10-1975] (Kiel, 1975)

Today, the bath, which is in a derelict and ruined state, was built using the masonry technique. Brick, iron, reinforced concrete, lime and cement mortar were used in work, especially freestone and rubble stone.

Figure 3.3. General view of the Hammam

The body of the building was formed using the alternating wall technique, in which brick beams are laid in the form of two or three rows between the side and rubble stone row. Stone material, which is generally used in the building's construction, was preferred in inhomogeneous rough cuts and rubble. During the recent interventions, it was observed that some of the walls were completed with stone materials similar to those of the building. However, the binding materials and craft used in these knitting are different from the original, clearly showing they were made recently. Apart from the main walls, stone material was used for the floors of the *soğukluk* (cool room), *hazne* (water tank) and pool in the middle of the *soğukluk* plus the pedestals/legs of the stokehole system.

Brick material, although it is mainly used in the domes and vaults on the top covers, was used in the door openings in the space transitions, in the arch braids of the *ılıklık* (warm room or tepidarium) and in the dome transitions. On the stone masonry main walls, brick material is preferred in the function of the beam, which is laid in two or three rows at regular intervals. In addition, terracotta pipe material was used in the water and potting installation in the masonry.

Lime mortar is used as a connecting element in the building masonry, top cover and floor covering. It was determined there were two separate plaster layers from the existing remains on the inner wall surfaces of the building (except for the cold and hot rooms). The red-colored rough plaster mortar is obtained from these layers by the mixture of lime and brick dust materials at the bottom, while the upper one is in the form of fine plaster mortar made with lime material. On the other hand, cement mortar is used as a bonding element in masonry in recent interventions or as plaster in places.

Iron material was used in the railings of the window openings, which are not original, on the eastern wall of the tepidity room and northern wall of the hot room during the recent interventions. The collapsed top cover openings of the warm and hot sections are covered with reinforced concrete plates.

In the middle of the 15th century, the work commissioned by Mahmud Pasha, the famous vizier of Fatih Sultan Mehmed, has important value in terms of being the only social structure of the Ottoman period that has survived to the present day in Serbia – Golubac. Built in a masonry technique using stone and brick, the work is the only type of hammam where men and women are used alternately. In Turkish hammam typology, it is located in the "domed center, transverse temperature and double halved type." The structure extending in a transverse rectangular plan in an east-west direction consists of undress, warmth, temperature, halvet cells, hopper and grinder sections. The hammam of Mahmud Pasha exhibits similar characteristics as a Turkish hammam in Anatolia and the Balkans in terms of plan type and architectural style (Figure 3.4).

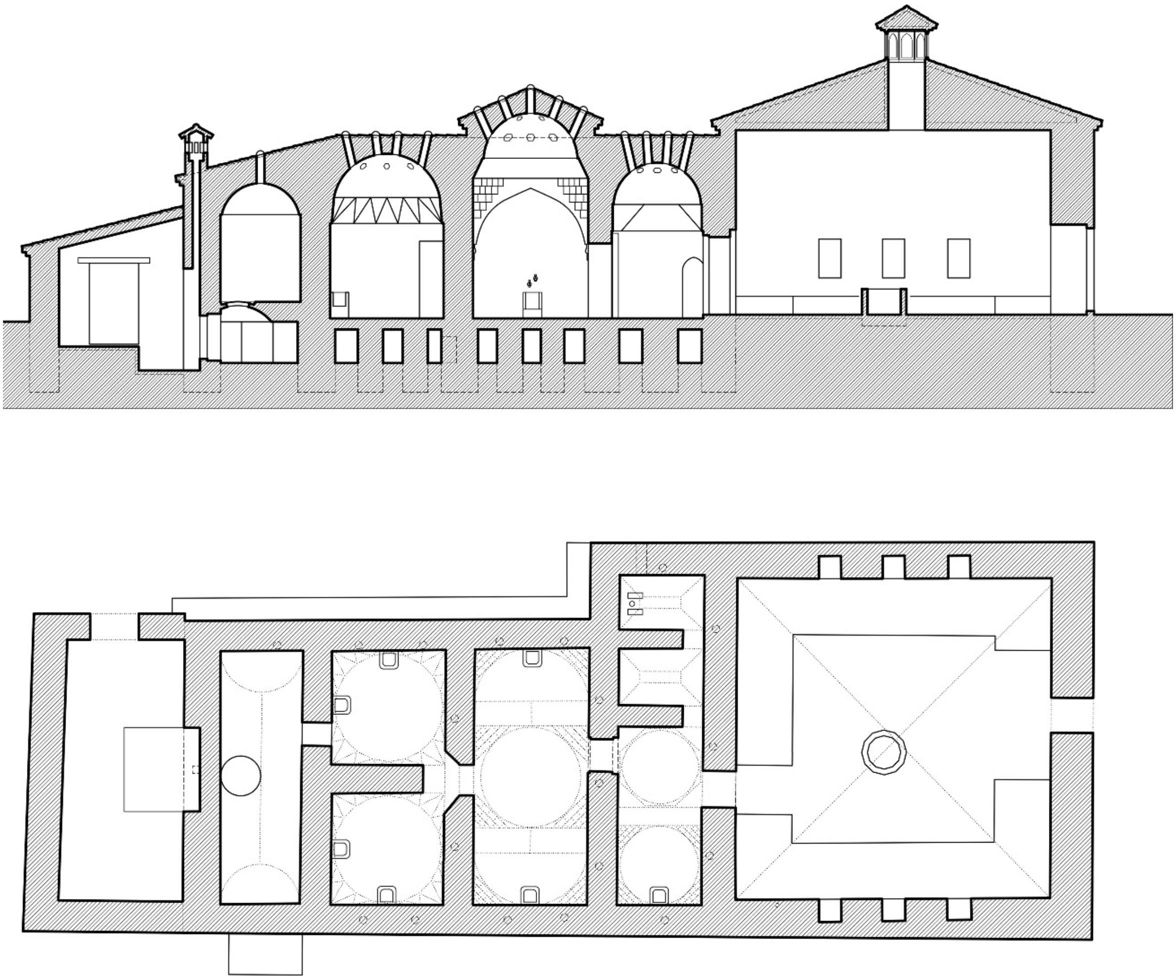

Figure 3.4. Plan and sections of restitution work for the Mahmud Pasha Hammam

Soğukluk: The *soğukluk*, which is the entrance of Turkish hammams, is also called the "camegah" or "*soyunmalık*." The *soğukluk*, which was usually large and showy, was covered with a dome or wooden ceiling. Depending on the size of hammam, there was sometimes a dressing floor (*şırvan*) made of wood. There were berms, couches, a pool and coffee stove for those who come to hammam. Hammams were an important part of cleaning culture and social life.

Tıraşlık: The *tıraşlık* was a place used for personal cleaning as well as by barbers. Besides barbers working from their own shops, there were also mobile barbers called "*ayak berberleri*" in hammams. Hammam barbers used to treat some skin diseases as well as shaving clients' hair and beards.

Ilıklık (warm room/tepidity room): The *ılıklık* is a place between the *soğukluk* and *sıcaklık*. People who could not stand bathed here. They would also sit here, relax and keep their body temperature stable due to the temperature difference between places.

Sıcaklık (hot room): The *sıcaklık* is the largest bathing place in Turkish hammams. It is also the most decorated part of the bath where, depending on the size of hammam, there are parts such as the *göbek taşı*, *eyvan* and *halvet*.

Halvet: *Halvets*, designed smaller than the *sıcaklık*, are sections that determine the architecture sheme of Turkish hammams. They are the hottest places in the hammams, since they are planned adjacent to the water storage room.

Hazne: The *hazne* is a rectangular planned and vaulted space adjacent to the *sıcaklık* and *halvet* sections, which is heated from the *külhan* and has a cauldron in it. Some hammams also have cold water chamber.

Külhan: This section has a stove where the water in the chamber is heated by burning wood. In some hammams, the *külhan* has a ceiling and in others it has no ceiling.

3.2.2. Specification content

The purpose of the technical specification is to ensure the architectural elements and values of the immovable cultural property, together with its environmental connections, are preserved, kept alive and included in contemporary life and to obtain all kinds of projects for its documentation; survey, restitution, restoration and various engineering projects. The works to be done for the works' purpose and qualifications are specified in the document prepared by the employer. The technical specifications contain detailed job descriptions to be carried out at different stages of conservation and repair projects. The scale and number of all drawing documents required in the stages of defining the building, analyzing it and explaining the forms of intervention are specified. The following projects and reports have been prepared within the scope of the work:

1. Survey drawings
   a. Drawings without comment
   b. Analytical survey (showing distortions)
2. Restitution proposals (restitution proposal is out of scope for this study)
3. Restoration project
   a. Interventions
   b. Demolitions (will be marked on the survey drawings)
4. Static projects
5. Mechanical projects
6. Electrical projects
7. Landscaping projects
8. Exhibition projects (the building is requested to be a museum)

A floor plan, ceiling plan, view of each façade and at least six section drawings are required to define the building. Produced projects reports will be delivered digitally (PDF and DXF) and in print.

3.2.3. Tools used in the documentation process

Two methods were used to reach the research result. The data provided to each technique is the same for the objectivity of results. A TLS, three cameras and three different lenses were used in the documentation process to obtain field data. In addition, samples were taken for material analysis, and a hammer, cold chisel and plastic bag for collecting material samples were kept ready in the field (Table 3.1. Tools used to obtain field dataTable 3.1).

Table 3.1. Tools used to obtain field data

Cameras	Nikon D80 10.2 MP DX-CCD	Nikon D90 12.3 MP DX- CMOS	Nikon D5100 16.2 MP DX-CMOS	
Lenses	Sigma 10-20mm f/3.5 EX DC HSM	Nikon 18-105 Af-s Dx lens		
TLS	Faro LS 120			
Main software	Revit	AutoCAD	SAP2000	
Substential software	Faro Scene	Autodesk Recap	Rhinoceros	Faro Webshare2Go
Other	Lazer meter	White balance card	Hammer, cold chisel	Bag for material sample

3.3. Research Process Plan

The restoration application project was initiated simultaneously with classical methods and BIM technologies, and the compatibility between the two ways and aspects that support each other was investigated (Figure 3.5). Furthermore, the adequacy and integration of HBIM applications within the framework of today's restoration understanding and expectations were investigated.

Stage-1: By doing literature research, the direction of current trends and future work in the studies were tried to be determined, so the strategy of the field study was designed.
Stage-2: It was aimed at obtaining a survey drawing and survey model. The 2D drawings to be exported with the Revit model were compared with the drawings obtained with AutoCAD.
Stage-3: The survey model's shareability was examined to make static analysis of the existing structure.
Stage-4: Restoration alternatives have been developed over the survey model. The costs of the prepared options were roughly determined.
Stage-5: It is about transferring the restoration model to SAP2000 software for static analysis.
Stage-6: It is about preparing the detailed approximate cost of the restoration model.
Stage-7: It is about obtaining a 2D application project over the restoration model and integrating it with the drawings obtained with AutoCAD.
Stage-8: All studies were evaluated pragmatically and future work targets were determined.

The study team examined the adequacy of the data produced at each stage in the context of technical specification requirements. It was decided on which method to proceed to the next stage.

Field data such as point clouds, photographs and videos prepared for both groups are common. Data for groups are not customized. This data was used for the production of 2D documents with AutoCAD and the model's output with Revit.

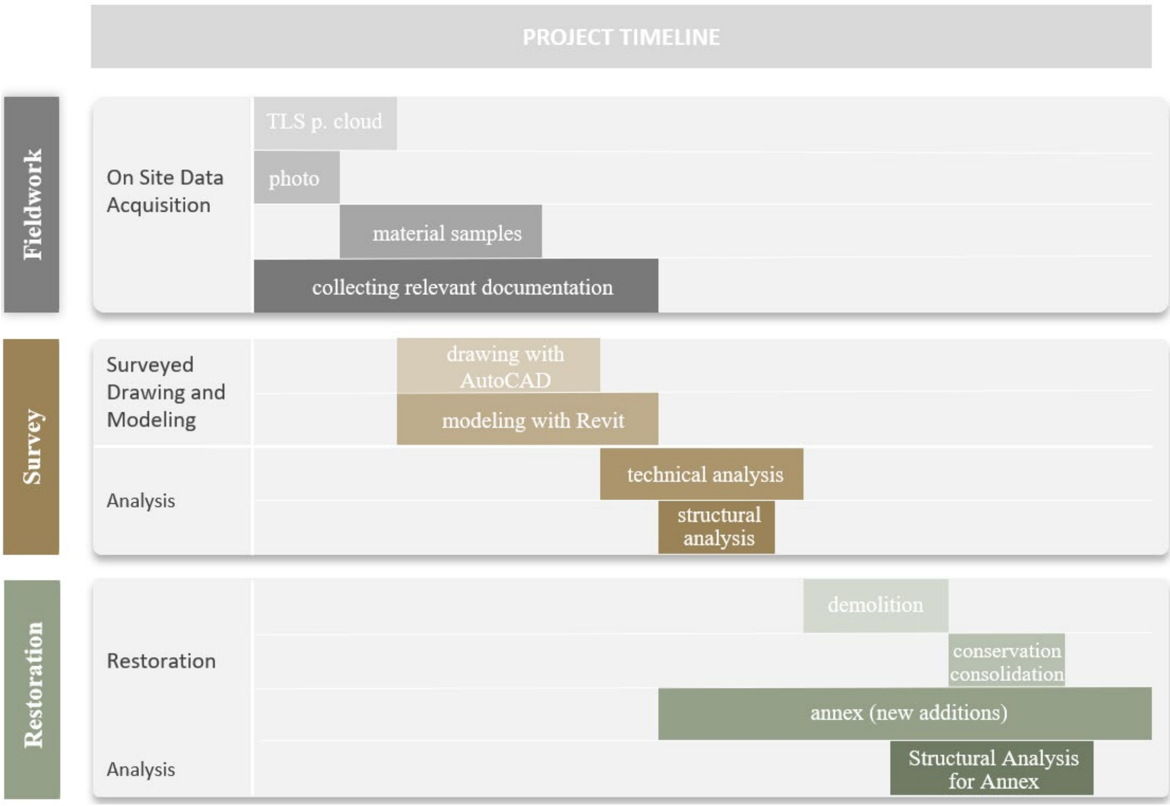

Figure 3.5. Research plan overview

3.3.1. Research method for data collection

As-found state data was obtained directly from the structure with the help of laser scanning and video cameras. Three teams established for this job checked their data and produced information in their field. Data on the history of the building were obtained from travelers, Ottoman archives and Serbian national archives. Material analyses were taken directly from the building and were made in the analysis laboratories in Turkey.

Collected data from site:

- Point cloud data
- Photos and videos
- Archival data
- Material samples for analysis

3.4. Research Plan for Data Analysis

Although the tools to be used and work to be done are clear, it is impossible to predict the workflow since using BIM programs during the preparation of a classical restoration project is a new scenario. Therefore, the contribution of BIM software was evaluated at every stage of the project, and positive and negative achievements were directly conveyed. The results of the trials were assessed from three main perspectives:

1. Documentation: The most crucial issue is obtaining the documents required by the specification. Outputs such as plan, section, view and preparation of approximate cost were evaluated in this category. (Objectives 5 and 6)
2. Data exchange: Benefit of one discipline to another through data exchange; secondary benefits are evaluated in this category. (Objective 3)
3. Visualization: Factors that contribute to the intelligibility of the project, such as visualizations, are evaluated in this category. (Objective 4)

Many studies in the literature point out the use of BIM is promising in achieving these criteria. The value of this study is that it is based on measuring the contribution of BIM use in a restoration implementation project.

3.5. Limitations and Responsibilities

The project was carried out according to the technical specification prepared by the employer. Each phase has a delivery date. The definitions, numbers, scales and delivery formats of the works to be done are clearly stated in this specification. Therefore, the produced documents have been prepared in accordance with the specification. Since the employer did not have a BIM request, the produced model was not delivered; only 2D documents were made and delivered in PDF and DXF media. The restitution study was excluded from the scope of this study.

4. CASE STUDY

This section conveys the experiments and experiences made in the workflow created for the Mahmud Pasha Bath. The order of the documents to be prepared for the building is specified in the technical specification (Section 3.2.2). The workflow followed the same sequence. First, the building's current state should be documented. For this, a 3D Revit model was prepared simultaneously with the classical methods of survey-analytical survey, using the data taken from the field. Then, restoration proposals were developed entirely on the Revit model, and the projects were produced using AutoCAD and Revit together. Finally, static models were made separately to strengthen the original parts of the building and examine the protection roof. Data sharing was discussed for both models (Section 4.5).

4.1. Restoration Approach of Mahmud Pasha Hammam

"The interventions should result from an overall integrated plan that weighs different aspects of the architecture, structure, installations, and functionality" (ICOMOS, 2003).

Mahmud Pasha Hammam is located in an archaeological area with a sheltered-controlled entrance on the Danube coast. The building is unusable and unvisitable. The site, operated by a private company, has a visitor reception unit with wet areas, a cafe, sitting areas, a small museum and administrative spaces. Although it is not far from the residential area, accommodation opportunities are limited in Golubac, a small town. Nevertheless, it can be seen by visitors with daily excursions. For now, a castle positioned on the rocks on the banks of the Danube, a bath and ruin thought to be a Roman house can be visited. However, it seems, if possible, excavations will be carried out in this area and new structures that are likely to be seen will be revealed.

It is suggested the building be used for an exhibition-museum function. Information about the structure, the bath culture, the person of Mahmud Pasha and the excavation will be presented in the museum. Although indoor spaces are needed for exhibitions in the bath, it is a situation that should be avoided as its roof and walls are heavily damaged; making it complete will result in obtaining a new bath and loss of originality. Considering the building is archaeological, it would be a correct approach to freeze the building. For this reason, a protective roof and shell proposal that can partially display the building's walls have been prepared.

4.2. Field Work and Measurements

A preliminary assessment was made with the team that excavated the building and information about the building was obtained. Opinions were exchanged on issues such as the condition of the land, area management, natural factors of the region, physical condition and building originality. Since the fieldwork was conducted in winter, the structure is under snow. The presence of snow on the building can affect the measurement of the TLS. This necessitated a rough cleaning of the building before measurement and photographic documentation. A roof cover made of wood was made to protect the building from external effects. This roof cover made working difficult, especially in the dressing area. The feet of the protective roof are very tight and the roof's elevation is relatively low.

Figure 4.1. *Soyunmalık*, a view under the temporary roof covering

The flooring of the *soğukluk* is original and the stones indicating the presence of a pool in the middle of the area can hardly be seen. As can be seen from the photo (Figure 4.1), the interior is dark due to the shallow height of the roof and the current state of the protective top has made it difficult to document the flooring. Increasing the number of laser scanning sessions to see the original flooring was also challenging to achieve.

There is almost no original flooring in the interior of the bath. Only a few of the brick legs supporting the floors have survived. The bath base is underwater and the soil has turned into mud. After the excavations by the local team, no filling was done again; it was preserved as it was excavated. The low ground level is an indication there will be a water problem in the building. This situation has been recorded as a large problem to be solved.

Although the structure was not very large, many scans were required due to the protection roof and feet holding the top. The Faro Focus LS 120 used for scanning is relatively small, which allows scanning of the channels under the floor that heat the structure. An 8.42 GB of data were collected by holding 83 sessions in and around the building (Figure 4.2).

Figure 4.2. TLS survey point map

One thousand, three hundred and fifteen high-resolution photos in NEF format and 23 long-length video images were taken with the Nikon D80, D90 and D5100 in the field to capture the building's current state. With office work, quality photos were obtained by adjusting the exposure settings of the images.

The collected data were combined with Faro Scene, the device manufacturer's software, using the cloud-to-cloud method, and were roughly cleaned and colored. As a result of combining the measurements, the standard deviation of the distribution of the points (Figure 4.2) is shown. The registration average between sessions was recorded as max. 9.902mm, min. 1.07mm. The mean deviation of all point cloud data was 3,531mm (Figure 4.3).

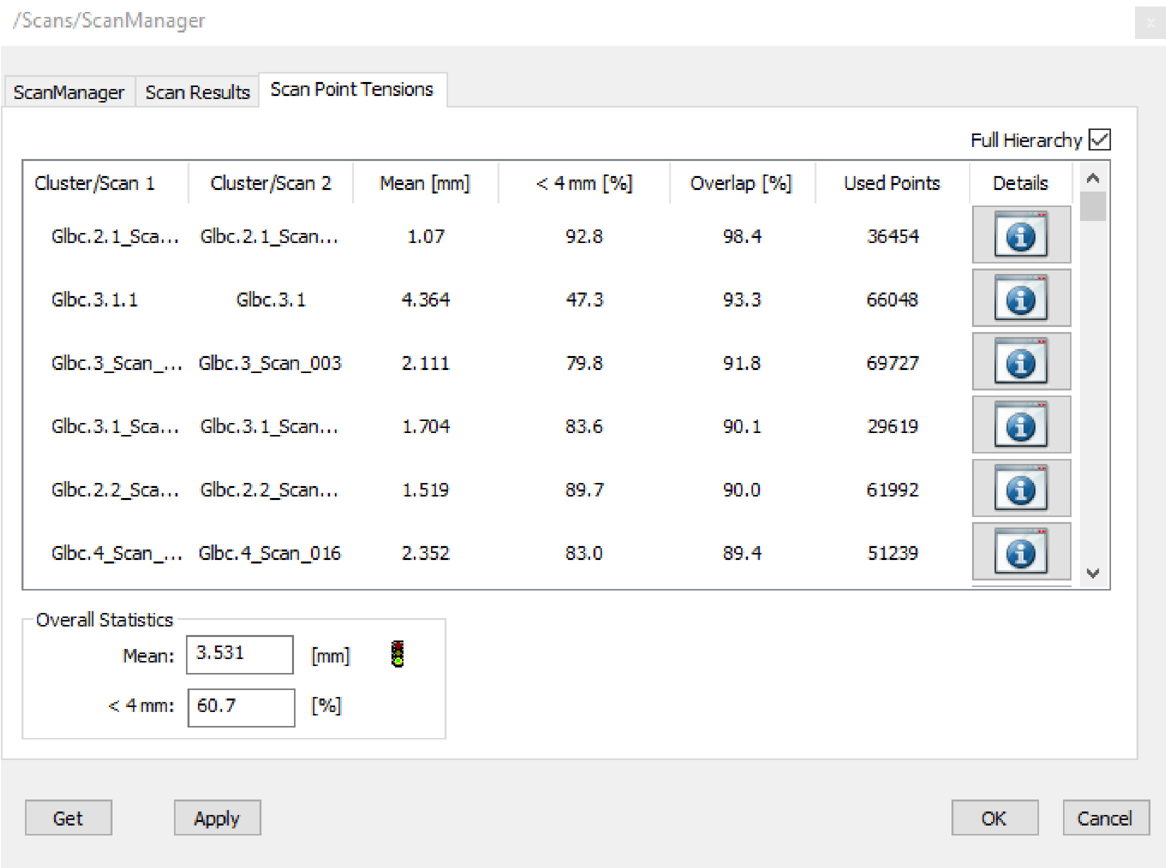

Figure 4.3. Point cloud registration result (standard deviation)

Data was transferred to WebShare 2Go, another software provided by Faro, which is web-based and offers 3D virtual tours with scanning data. Thus, colleagues who did not see the building in its place could better understand it. The fact this file does not require any software installation and is portable due to its size has facilitated cooperation with stakeholders.

Although there is a similar feature in Recap from the Autodesk software group, WebShare 2Go seems to be more advantageous in size and working speed. A web window makes it possible to see the plan plane, 360 views and a 360-degree view of the selected scanning point (Figure 4.4). In the case of scanning in insufficient color, it allows the user to choose the color and black-and-white images (Figure 4.5). This feature is used when the color information in the laser scan data makes it difficult to read the structure.

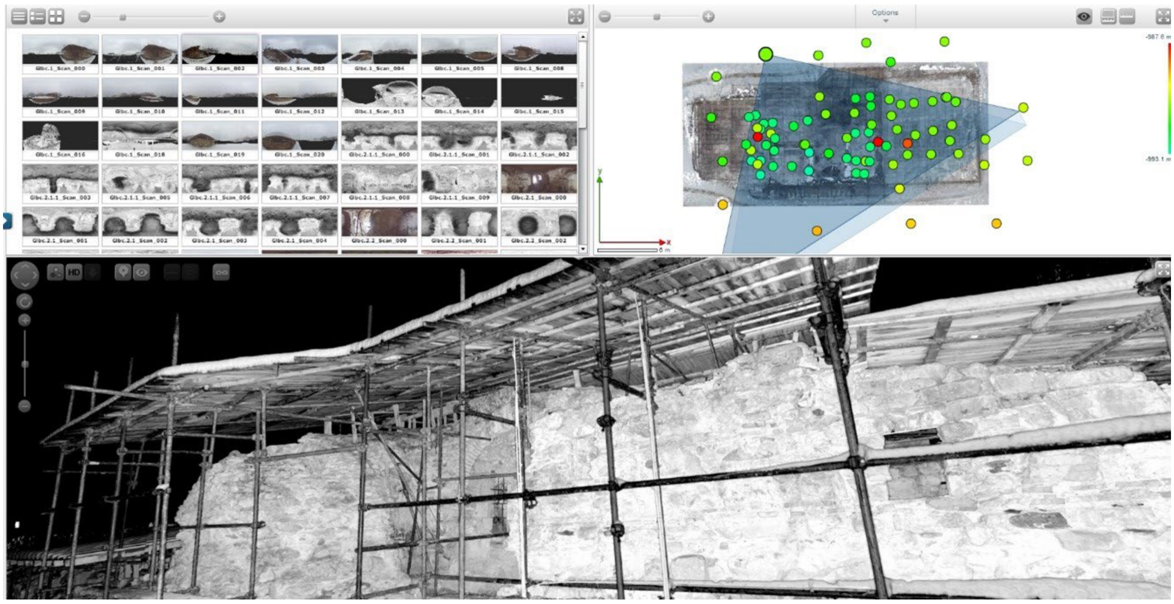

Figure 4.4. WebShare 2Go user interface

Figure 4.5. WebShare 2Go viewing alternatives, coloured or black-and-white

Data obtained with Scene, the software provided by the device manufacturer, cannot be used directly with CAD or BIM software. Therefore, the point cloud needs to be converted according to software preference. Since AutoCAD and Revit will be used in this study, scans were converted to Rcp-Rcs format via Autodesk software Recap (Figure 4.6). Thus, the point cloud is ready to be imported into the AutoCAD environment for drawing.

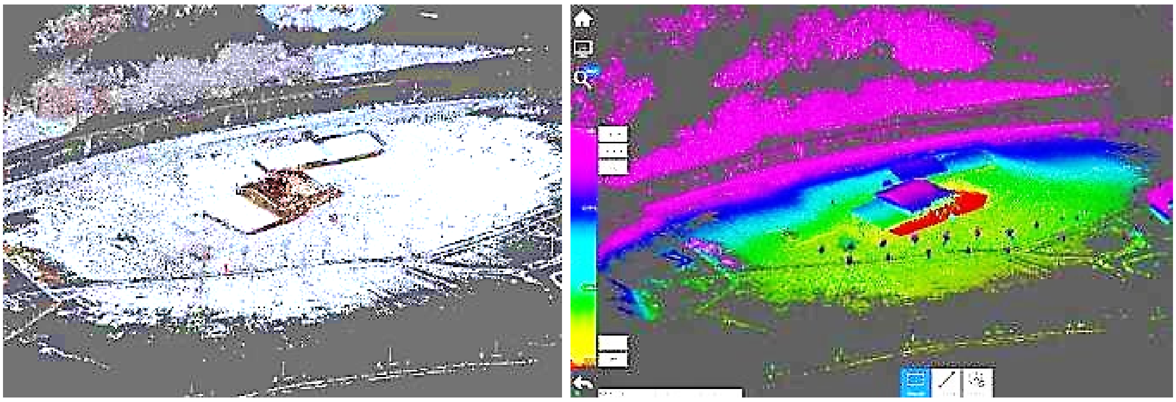

Figure 4.6. Recap view, all collected point cloud from the site

Scene software includes advanced manipulations such as reducing the size of the point cloud by making it a composite point cloud with different filters. In this case, the color and tonal differences between the scans can be eliminated, and a lighter point cloud can be obtained by removing very close points. However, in this case, the features offered by AutoCAD or Recap software, such as importing each session independently opening and closing in the drawing environment, are deprived. Also, there is a significant difference in size between the overall size of a single file and a fragmented file system. Although the fragmented nature of the ununified point cloud may seem confusing, its customizability makes a significant contribution. For example, an operator who draws a north façade can work on a lighter model by removing unnecessary points. Another advantage of this method is that it allows us to see more clearly. Points from two side-by-side sessions can distort each other's clear view. In this case, it is a good experience to log on and off based on the must-see area.

Too large a point cloud can make it difficult to control in a CAD environment. It is usual to rotate the point cloud (orbit) to understand the drawn object better while drawing. The small point cloud facilitates this process. For this reason, the structure perimeter was cut out and turned into a single-point cloud.

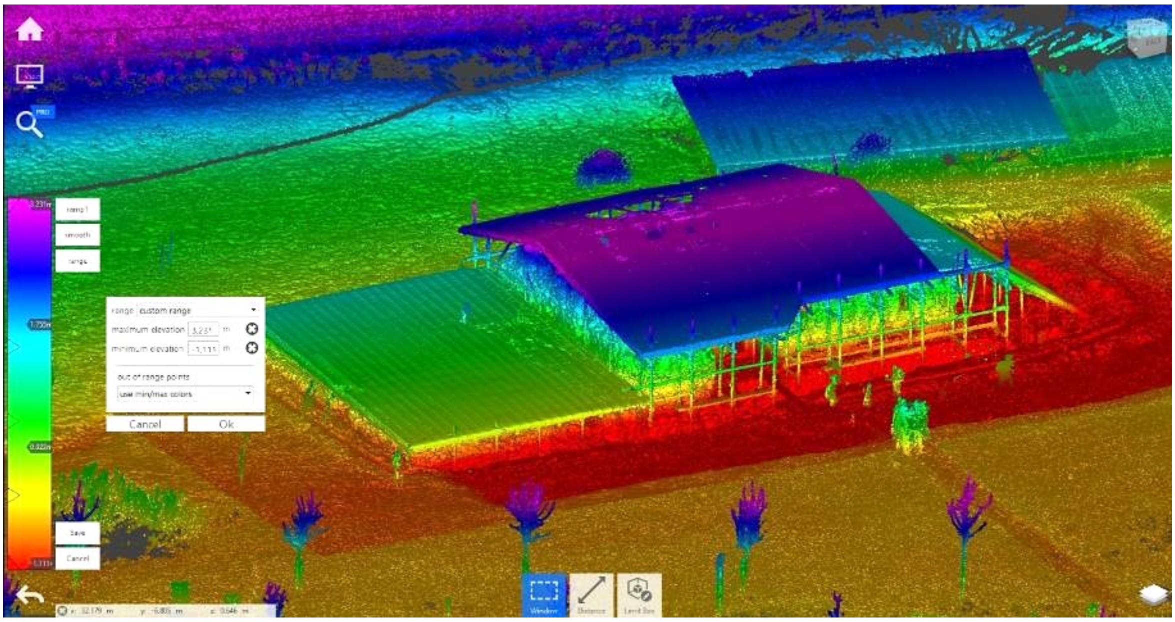

Figure 4.7. Point cloud data, cleaned and aligned to zero

Recap software can organize unregistered scan sessions, wipe out unwanted spots or create a hierarchy with the help of layers (Figure 4.7).

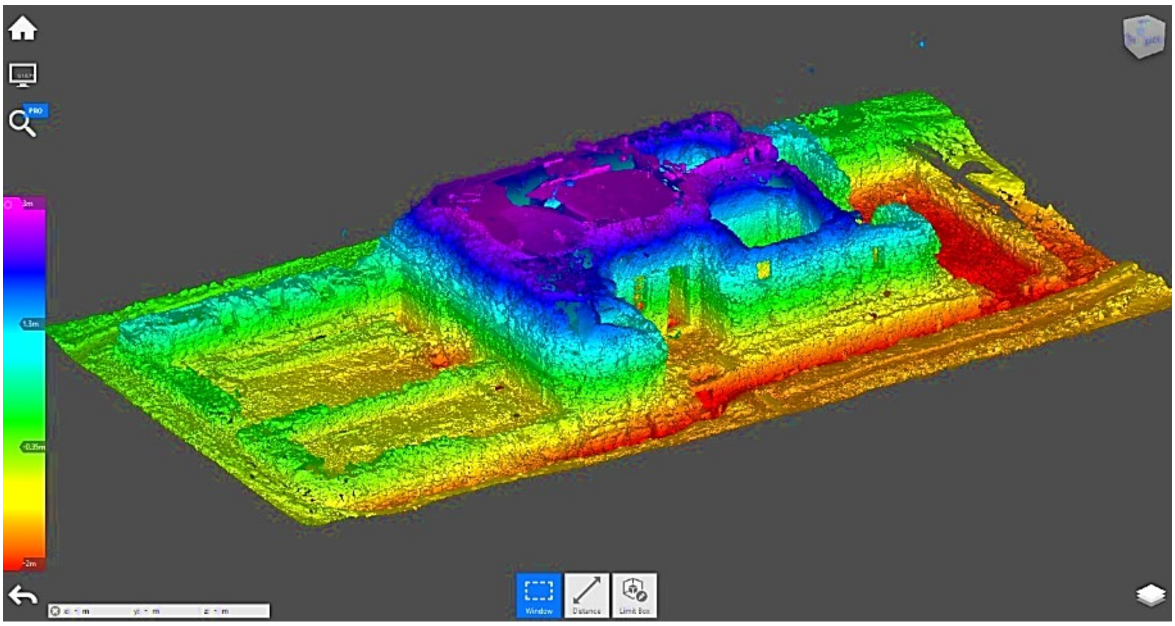

Figure 4.8. Point cloud data ready for drawings by deleting irrelevant objects

A more understandable point cloud was obtained after the protection roof, which was made to prevent the building from being affected by natural conditions such as rain and snow, was cleaned with Recap. But inevitably, unmeasured areas occurred due to the protective roof (Figure 4.8).

4.3. Survey Phase

Six plans, four views and 16 sections were drawn using AutoCAD software to determine the building's current state. In addition to the classical method used to prepare the surveys, modeling was done with Revit and Rhino, and the two methods were compared.

4.3.1. Classic method, creation of 2D drawings

The creation of drawings by the classical method can be done in several ways. The first of these is the generation of orthophotos over the point cloud and drawings from these photos. This method can be controlled more easily without tiring the software and hardware. This method can be easily used on computers with lower configurations. The small file sizes make the project portable. It is common practice to use orthophotos in some cases, especially in reporting. However, another step has intervened in the workflow, bringing additional workload.

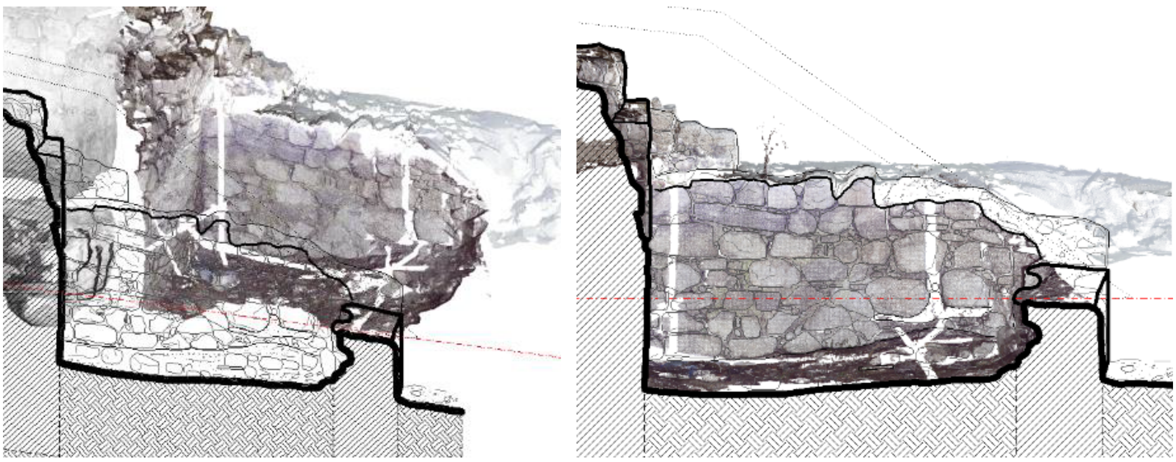

Figure 4.9. Drawing on point cloud (AutoCAD)

It is also challenging to understand the depth of an object in orthophotos. Depth is a factor that strengthens expression in drawing (Figure 4.9). Therefore, telling how far ahead or behind a thing is one of the success criteria of the survey. In addition, care was taken not to change the data provided to compare the Revit and AutoCAD processes.

The second method in preparing the survey is to import the Point Cloud directly into the CAD software and draw on it. Thus, using the depth information of the point cloud, the depth of the objects can be seen very quickly, and understandable drawings can be prepared by interpreting them correctly (Figure 4.9). However, the point cloud size can make it difficult to control in CAD software. Therefore, the computer's configuration to be used must be high level. The on–off status of measuring points can be checked with the built-in point cloud control tool (Figure 4.10). Thus, the illustrator can open sessions to alleviate the point find and obtain a more precise image (Figure 4.11).

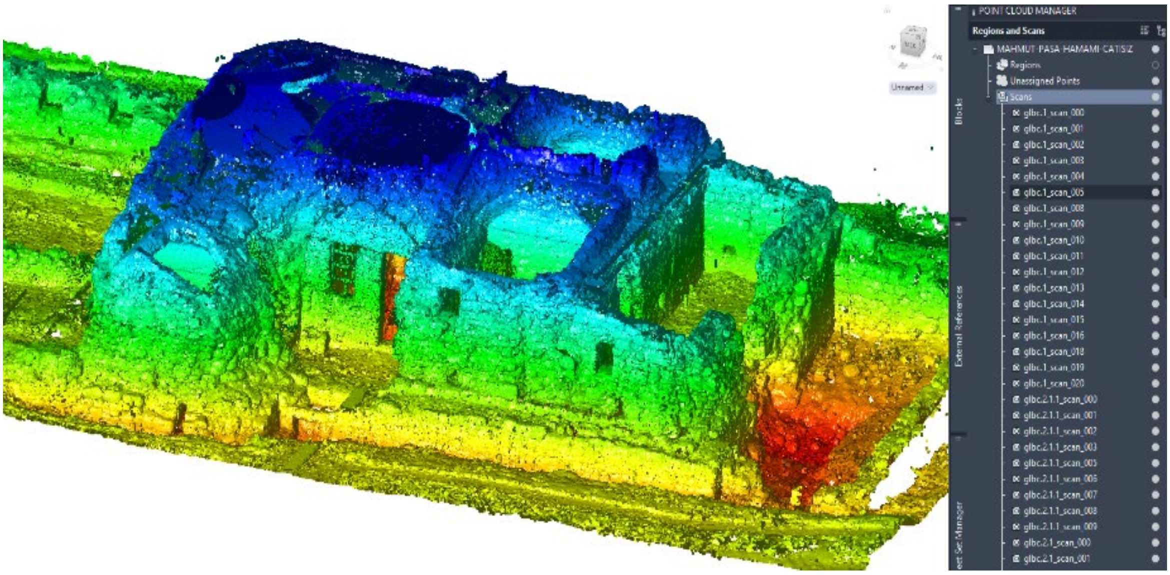

Figure 4.10. Point cloud view in AutoCAD

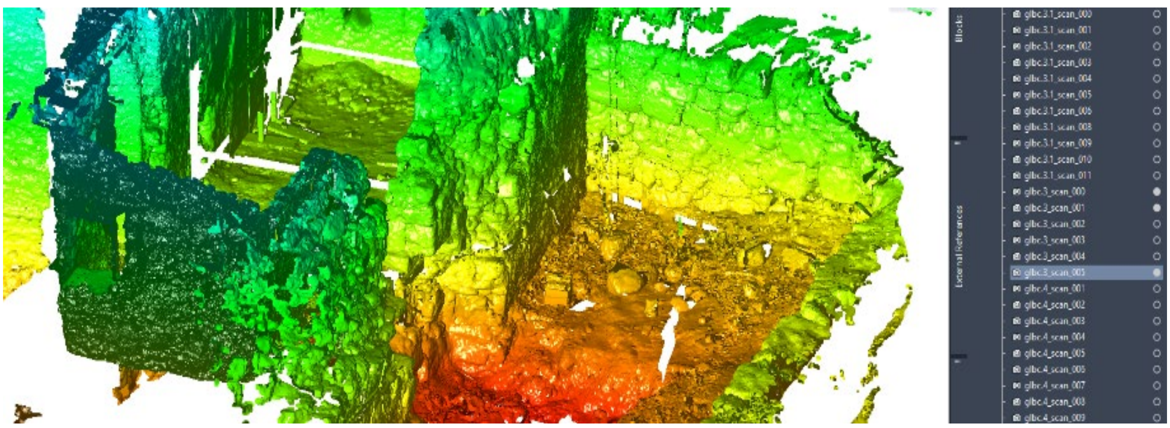

Figure 4.11. Point cloud session selection with AutoCAD Point Cloud Manager

In this project, drawing directly on the point cloud was preferred. The reasons for choosing this method can be listed as:

1. Since there are so many organic forms that need to be displayed in the structure, it has become essential to see the depth of the object through the point cloud. In Figure 4.10 and Figure 4.11, gaps can be seen in the measurement. Such problems can be seen in measurements made on organic surfaces. In the orthophotos produced for such structures where the even distribution of points is not possible, the objects located further back may appear due to gaps in the point cloud. This situation can cause great misunderstandings.
2. Once the orthophotos are produced, a static workflow emerges. It can be pretty tricky to detect misproduced orthophotos. Since each drawing representing a building, such as a plan, section or view created from different photographs, inconsistency in the drawing is possible. The point cloud is added to each drawing as an external reference, and the drawing is made over it. Since the source is single, the changes made by one user are transferred to the others, thus creating a dynamic process.

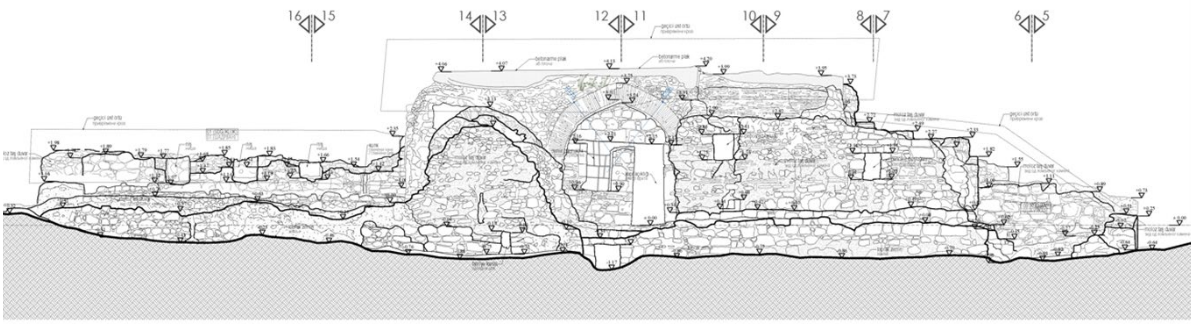

Figure 4.12. A view surveyed drawing obtained by the classical method

A single drawing was created in each file, a surface was drawn only once, and it was added consecutively with the Xref method according to the direction of the section or view. For example, the façade view shown in Figure 4.12 was created by combining three DWG files as Xref. Since each surface was drawn once, no work was duplicated, and any change that could be made was automatically transferred to all relevant drawings. In this way, a group work environment, efficient workflow and consistency in the information produced were achieved by enabling a document to being created by several people together.

4.3.2. Analytical survey drawings

The problems in the building were examined under the headings of structural issues, material deterioration, problems caused by environmental factors and unsuitable additions-interventions (Figure 4.13). They were processed using the mapping method on the survey drawings (Figure 4.14). Making the drawings graphic makes the explanation easier. However, some types of problems cannot be explained on drawings. For example, building components that exist in the building but do not exist in the current situation are considered problems or the problems related to legislation cannot be explained visually. Therefore, all problems – shown graphically or not – are described in detail in the survey report.

This stage will form the basis for the consolidation study, one of the sub-headings of restoration. Restoration decisions were made as a result of the restitution study and analysis.

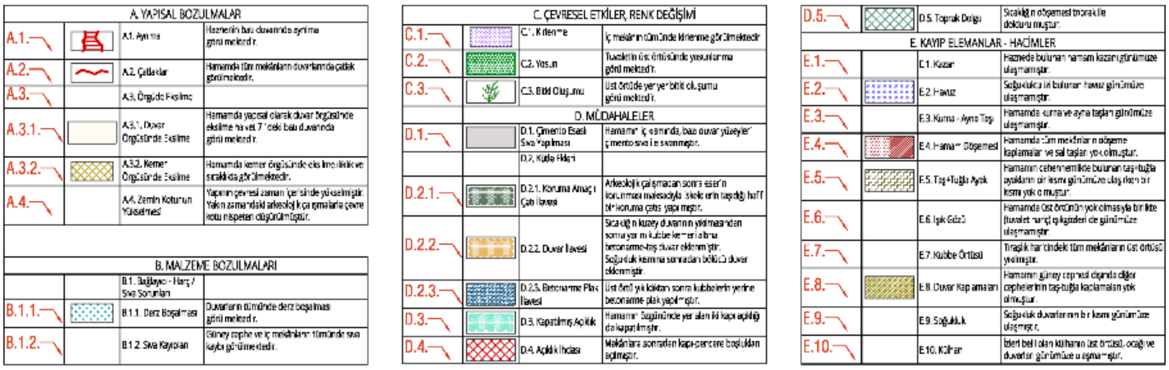

Figure 4.13. Legend of deteriorations

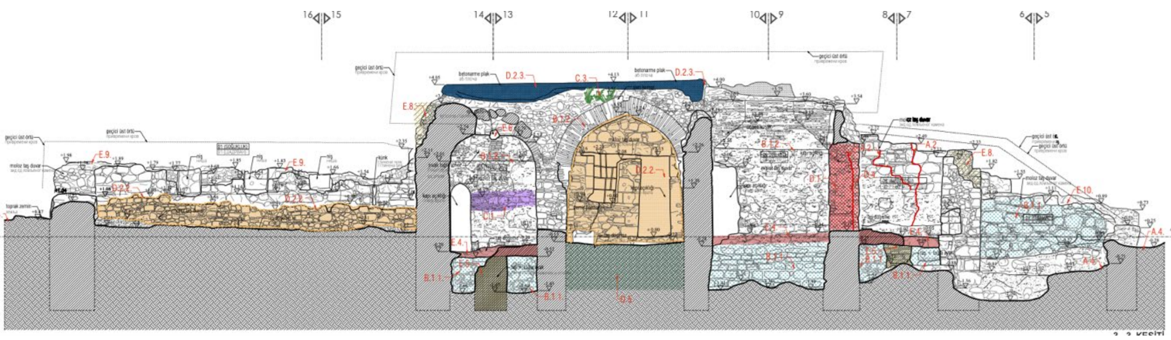

Figure 4.14. Defects/deteriorations mapped onto the survey drawings

Due to the overlap of some problems in the structure, it was often necessary to make revisions in hatches and colors. For example, plaster losses, moisture and algae problems may overlap. However, such issues can be easily solved by changing the colors and textures of the scans in 2D drawings.

4.3.3. Survey model

While the surveys were being prepared with the classical method, another team started modeling the current situation. The first attempt was made with Revit from the Autodesk software group. This software is trendy in the HBIM field, with no pretensions for modeling heritage structures (Figure 2.4). The second trial was made with Rhinoceros software, which stands out with its practical and lightweight system in 3D production, although it is not BIM software. According to the workflow, which has many examples in the literature (Capone and Lanzara, 2019), it is aimed to import the produced model into Revit.

Modeling with Revit

With Revit, a model with unique components can be created in several ways. The first of these is the use of modules such as walls, floors and roofs provided by the software. Revit requires that objects be linked to the typology to maintain consistency. But unlike new buildings, it is possible to see walls of more than one thickness in a heritage building, even though the organizational scheme is the same (for example, a stone wall). To model walls of different thicknesses, it is necessary to create more than one wall type. The same is true for all modules (floors, doors, windows). Thus, creating a parametric library that represents a product group for only one object is necessary. Unfortunately, this is not an efficient method. The user loses time to find the proper library.

Second, there were control problems at the junction points of the objects. When modeling an existing structure, more than one type of junction may coincide with a point. For these nodes to appear correctly, the join command must be given. In this case, the Revit behavior was found to be inconsistent.

The third problem is that constantly giving join commands is a workload. It also exhibits inconsistent behavior when moving an object from merged objects. For example, the position of a wall you designed may have changed later. It is a near-impossible task to check whether objects have moved at each stage of modeling. As a result of these determinations, modeling using the built-in standard modules offered by the software was considered inefficient, and the second method, mass modeling, was tried.

Although mass modeling is basically a solid modeling method, the class of the produced object can be determined (Figure 4.15). Although it is not possible to create parametric objects with this method, the created object can communicate with many tools and can be distinguished in quantity lists. Thus, although parametric objects cannot be obtained, a model that can be filtered in tables and lists can be produced by assigning the object category.

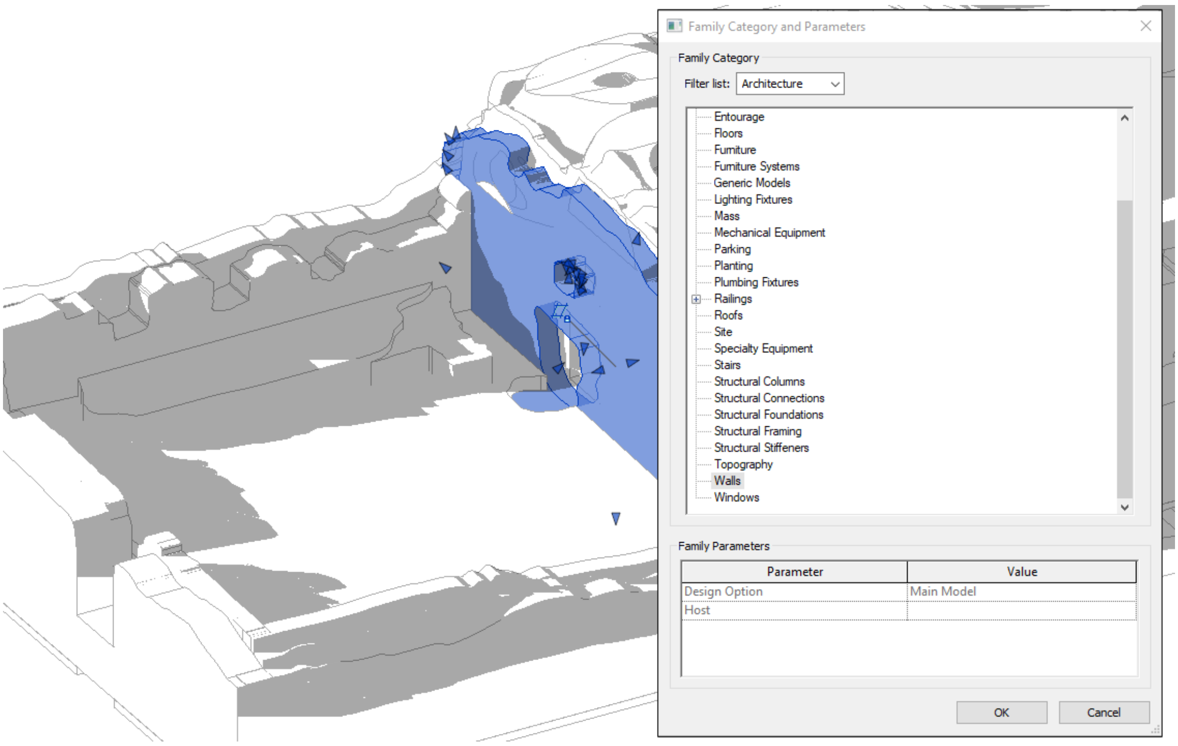

Figure 4.15. Mass modeling, family category and parameters

The solid modeling approach has several other advantages. Boolean operations tools (loft, sweep, revolve) can be used to model objects (void or solid), and this toolkit provides a more flexible modeling environment. Although the non-parametric nature of the objects obtained by this method may seem like a negative situation at first glance, since the interaction of the objects with each other is very limited, a problem such as accidental displacement does not arise. It is suitable for modeling a static situation such as a survey.

The two methods described for the Modeling of Mahmud Pasha Hammam were compared, and the second method, mass modeling, was preferred. Consistency was the most important factor in the choice. It is not acceptable for the behavior of a generated object to change randomly. However, moving away from the native tools offered by the software is not a recommended method and does not suggest an effective process. Because there is software (not BIM) that can produce models more easily using this method.

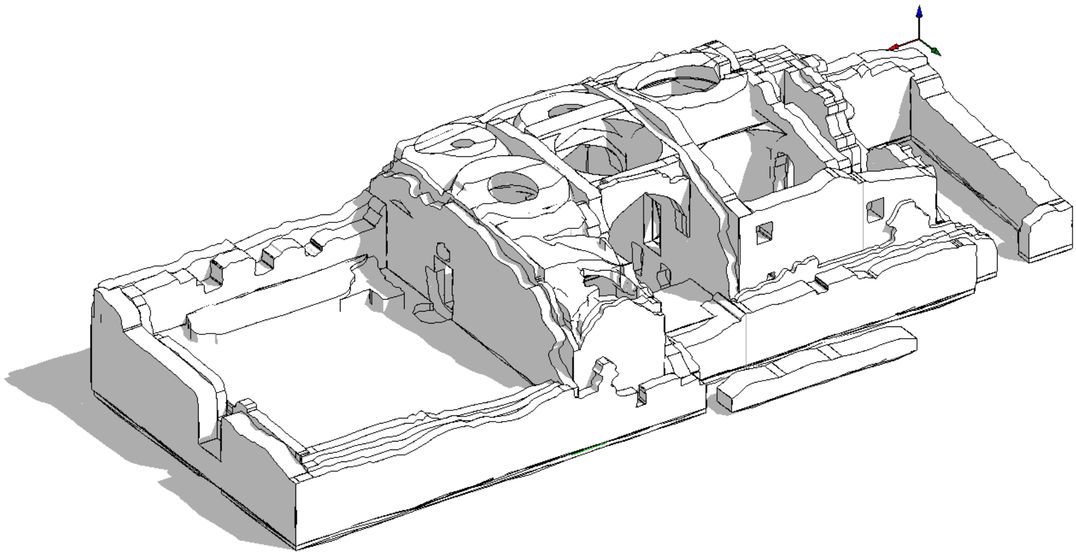

Figure 4.16. As-found model produced with Revit from the survey

The walls of the building are made of rubble stone. In this technique, a filling consisting of large stones and mortar is made inside the wall by lining up the stones from the inside and outside and making the stones act like molds (Cali, 2020; Tayla, 2007). To transfer the elevations formed on the inner and outer surfaces of the damaged wall to the model, the wall was modeled by imitating the 2-3-stage wall construction (Figure 4.16).

When modeling the wall foundation, it can be used directly from the point cloud. However, elements such as the dome and vault are modeled in a slightly more complex way. In order to model an existing damaged dome, its undamaged state must also be known. The reason for this is the necessity of constructing the geometric shape on the correct parameters. For this reason, a full dome was designed according to the walls on which the dome sits, compared with the point cloud, and subtracted by modeling separate masses for the parts that did not survive. As a second method, a complete dome was divided into two as existing and missing, and a visual was obtained by entering the manufacturing and demolition dates for these two parts with the phasing tool (Figure 4.17).

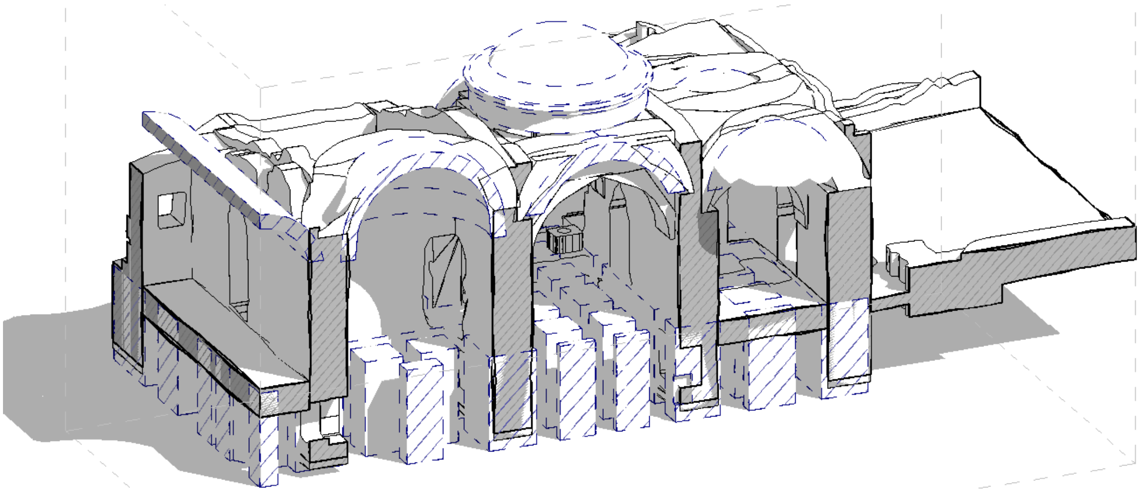

Figure 4.17. A presentation of the construction-demolition times with the phasing tool

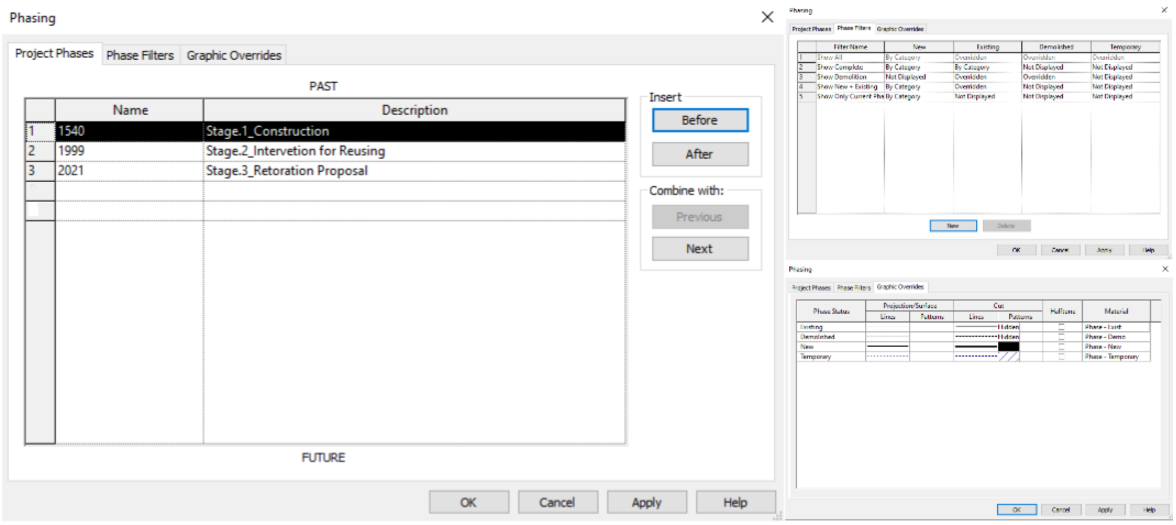

Figure 4.18. Building phase interface: (a) Project phases, (b) Phase filter, (c) Graphic overrides

It has been seen that the phasing tool, one of Revit's tools, can be useful in modeling (Figure 4.18). Production or dismantling/demolition date information can be added for parts made or destroyed in different periods, and these filters can be used when creating documents and 3D images. For example, the dome, which was determined to have existed in the mid-1500s, was partially destroyed in the 1900s. It is also possible to show the brick feet that carry the floor of the bath and provide heating of the building by carrying the hot air, which do not exist any more (Figure 4.17).

Modeling with Rhinoceros

The production of organic and non-standard models with Revit is not easy compared to software such as Rhinoceros. The variety of software used to produce HBIM in the literature supports this view. Rhinoceros stands out among the software that supports Revit as a model (Figure 2.4).

Using AutoCAD, the point cloud was cut every 25cm in the XY plane and a polyline was produced automatically. Mesh production was made in Rhinoceros software by means of these lines. As explained in Chapter 4.5, voxel models and mesh can be produced with a polyline. Thus, it was decided to test this procedure.

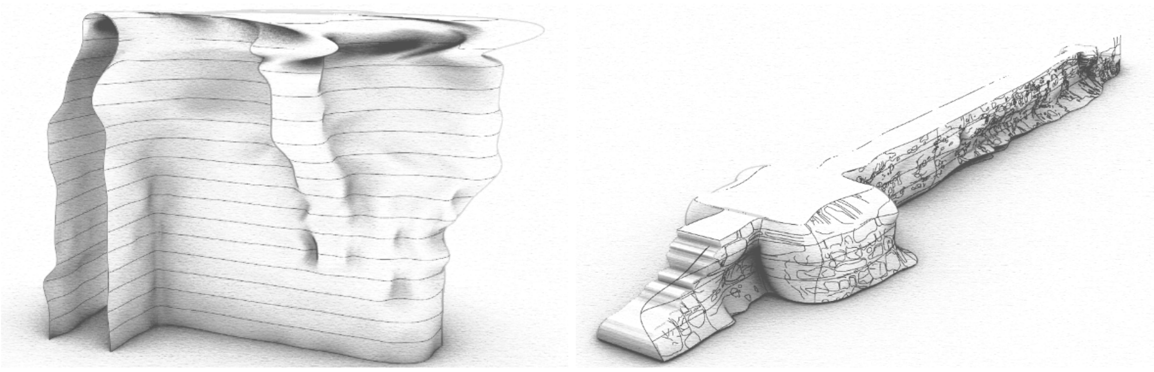

Figure 4.19. (a) Reflecting the stones drawn with AutoCAD to the mesh model, (b) Generated mesh model from polyline (12.5cm)

To develop the model obtained with the polyline passing at 25cm intervals, lines with 12.5cm intervals were produced and used for the model (Figure 4.19-a). However, due to the type of stone used for the wall and shedding of the coating, the irregular structure of the wall surface caused anomalies such as the formation of folds in the model (Figure 4.20). Although it is possible to add the drawings prepared with classical methods, namely AutoCAD, on the mesh produced with Rhinoceros, an appearance that gives the right impression only when viewed from the front is obtained due to the inclination of the surfaces (Figure 4.19-b).

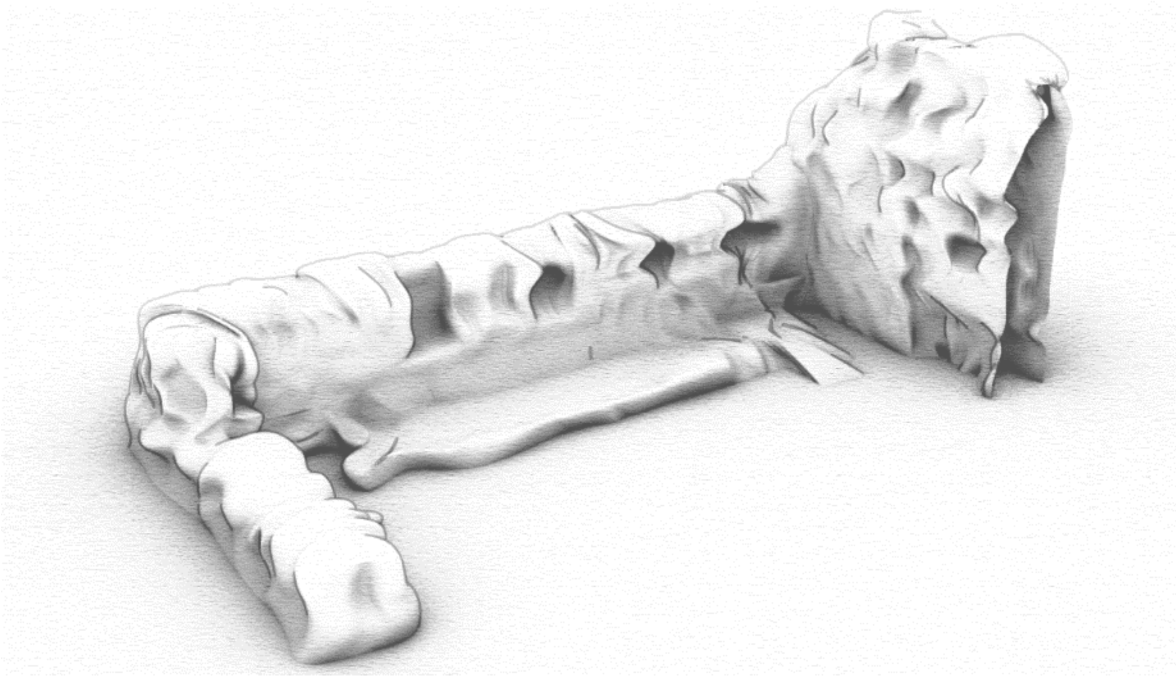

Figure 4.20. Generated mesh model, *soğukluk* wall

4.4. Restoration Project Phase

In this section, the qualities of the drawings to be prepared within the scope of the restoration project and the methods followed are explained. The relationship of each stage with BIM software was evaluated and the produced documents were exemplified. A survey was prepared for the building, the problems identified in the building were marked on these as-found drawings and material analyses were made. Restitution was prepared by researching the building's history. The parties of all these studies that look at the implementation project will be evaluated at this stage. The tasks to be prepared within the scope of the specification are listed below:

- Demolition drawings
- Restoration project
  - 3D alternatives
  - Consolidation and annex
- Static project
  - As-found state analysis
  - New condition analysis

Unlike a typical restoration project workflow, the BIM approach was included in the process in this study and the workflow diagram was updated according to the results (Figure 4.21).

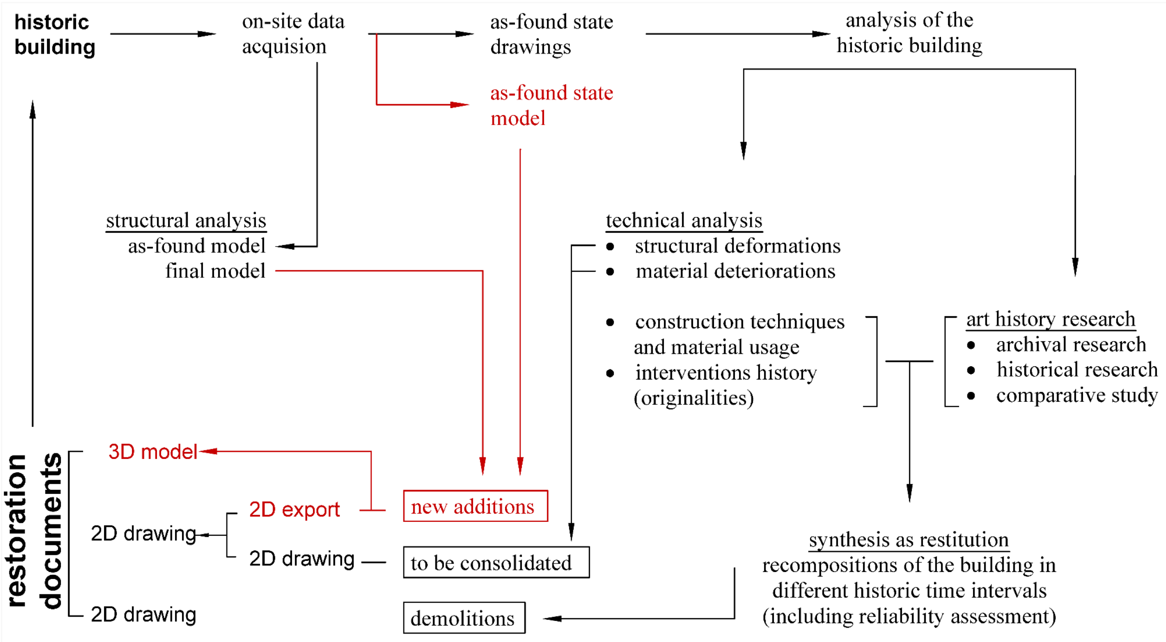

Figure 4.21. Proposed BIM approach integrated workflow (red color indicates Revit's work)

As shown in the diagram, most of the process was prepared with AutoCAD. The main factor is that the as-found model prepared with Revit is insufficient to document. However, the nature of the selected building and restoration approach allowed the restoration interventions to be divided into two. First, strengthening and consolidation of the existing structure were prepared in 2D with AutoCAD. Then the annex (new additions) was created in Revit. The parametric nature of the prepared model significantly accelerated the static calculations and the feedback processing in the project and reduced the margin of error. The 2D drawings created with the Revit model were exported as DXF and an application project was completed with an integrated workflow.

4.4.1. Demolition drawings

One of the most critical stages for restoration work is restitution. In the restitution study, the current situation was examined, comprehensive reports were prepared, the parts that should be removed were determined by evaluating the periods and they were shown on the DXF drawings. As a result of this study, the original parts of the building are distinguished.

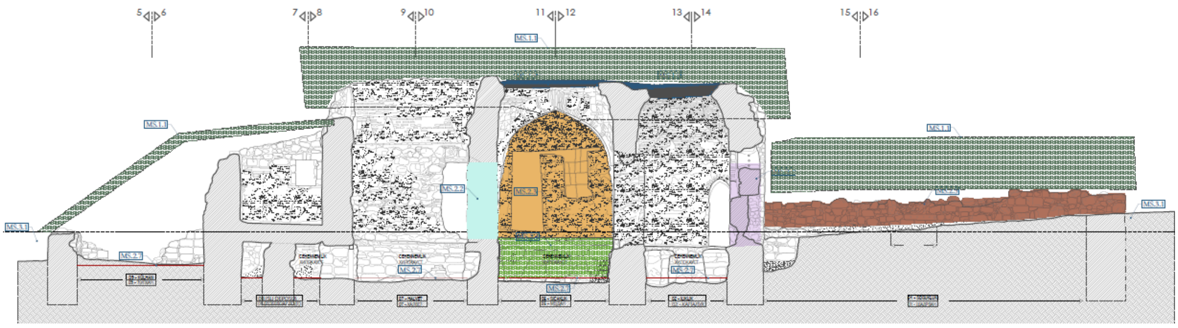

Figure 4.22. Demolition drawings, section

Demolition decisions can be shown schematically with the Revit model and phasing tool. Still, since the survey and problems were prepared in 2D, demolition drawings could be prepared more quickly and effectively with AutoCAD. The decisions of the masses to be removed (Figure 4.23-b-c) in the current state of the building, such as the protection roof and scaffolding bars, the unqualified wall built under the arch (Figure 4.23-a), the concrete slab on the dome and the fillings on walls, were mapped on 2D documents (Figure 4.22).

Figure 4.23. Demolition parts of building: (a) Concrete wall, (b) Cover roof and undervalued wall, (c) Window

4.4.2. Restoration project

The building restoration is the product of an international effort. It should be taken into account that each country has its decision-making mechanisms in its internal affairs and the proposal discussions can take a long time. Many parameters can be said to accelerate the process, but the presentation technique will be emphasized in this study since the subject is technical requirements. As mentioned earlier, documentation and presentation have a very important place in decision-making processes. The easier the current situation and recommendations can be understood, the faster and more accurate decisions can be made.

The reason for the failure in modeling the survey is the misuse of the software. There is currently no specialized software for HBIM on the market. The design/modeling of existing structures, especially those in dilapidated condition, is one of the usage scenarios outside the purpose of BIM software.

Although the survey model fails in two aspects (documentation and sharing), it is still usable for visualization. The dimensions of the model are not in millimeter precision, but there is no negativity in roughly expressing the structure’s state.

Preparation of restoration proposals

This section aims to discuss the restoration proposals prepared with Revit with all their stages and the qualities of these proposals. Four protective shell proposals with different qualities were prepared on the as-built model. The material list and quantities of each proposal could be prepared quickly. Additions are calculated not only in terms of cost but also for static analysis. It can be seen that three of the suggestions (Figure 4.24, Figure 4.25 and Figure 4.27) transfer their loads directly to the soil and do not impose any load on the structure. In one proposal (Figure 4.26), a system was developed in which the building carries the loads to emphasize the bath’s original state.

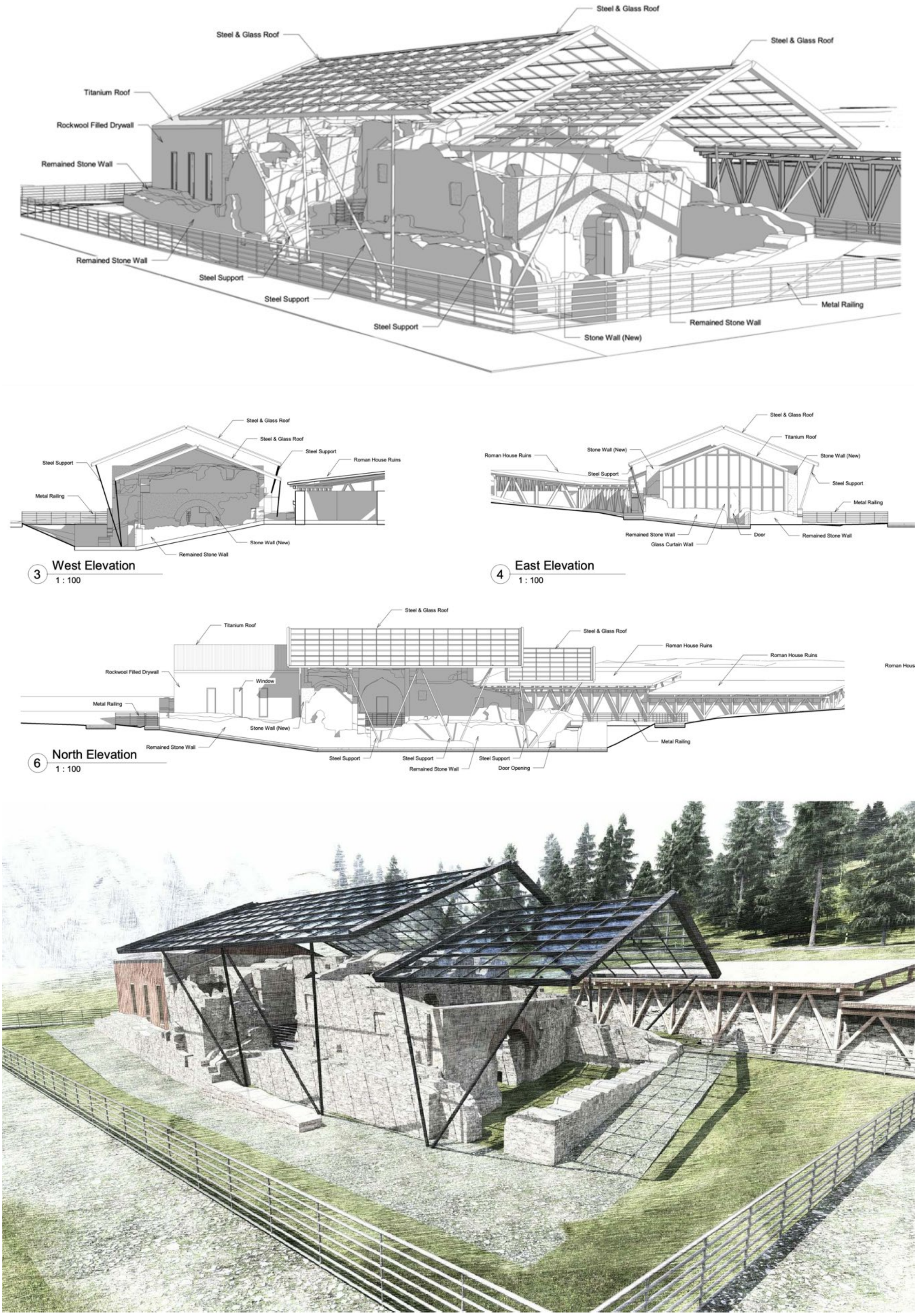

Figure 4.24. Restoration proposal 1, light structure

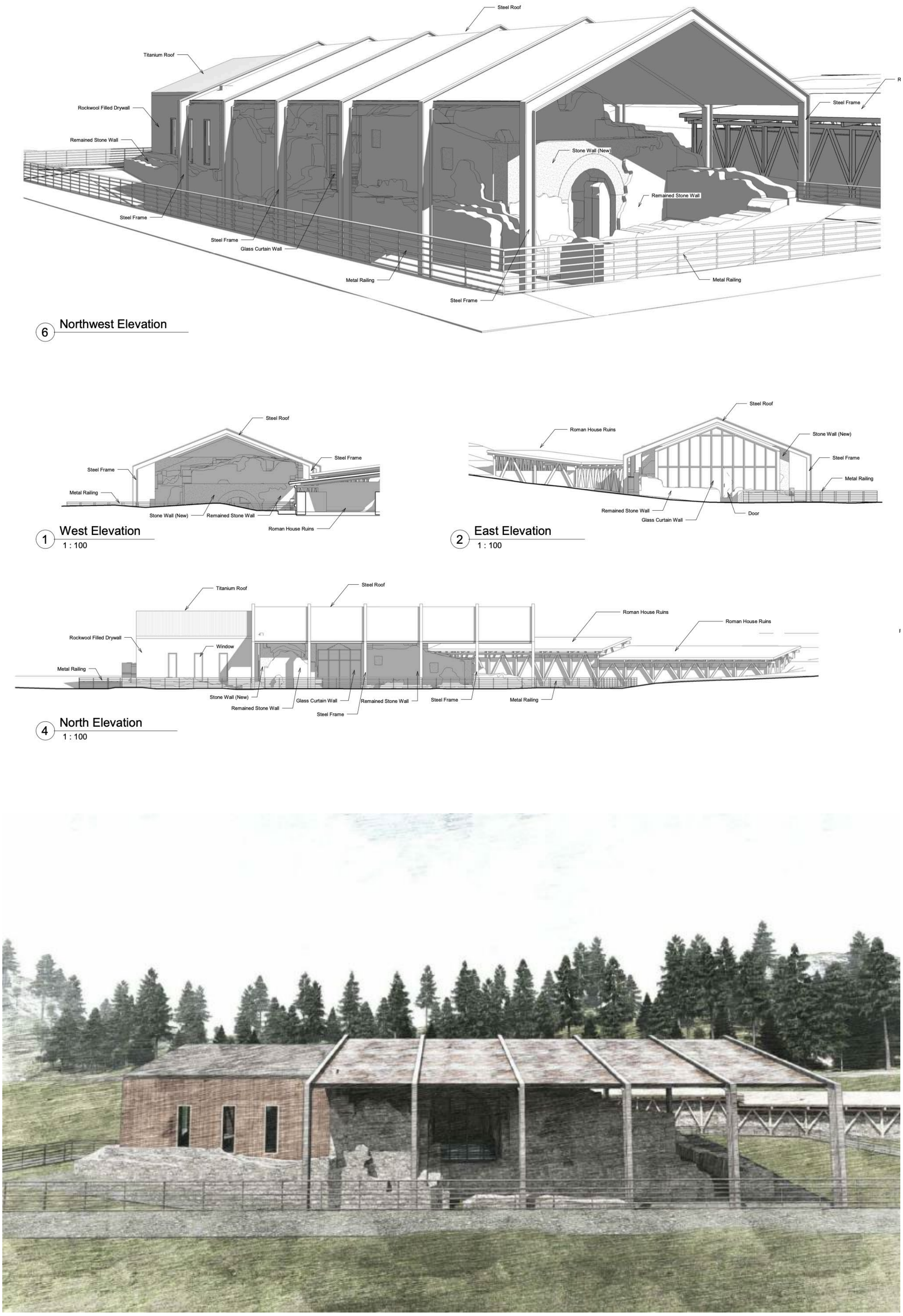

Figure 4.25. Restoration proposal 2, cheapest alternative

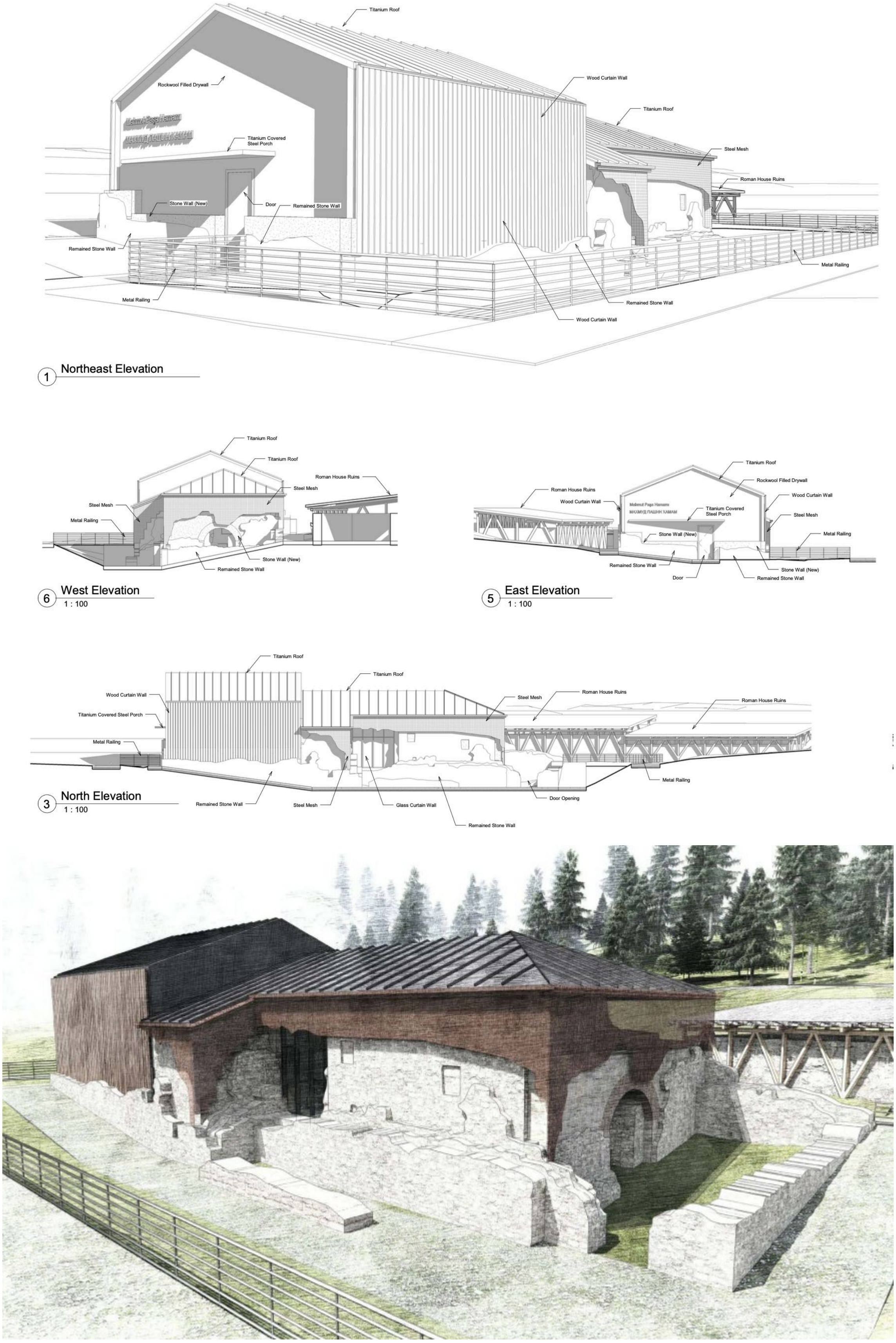

Figure 4.26. Restoration proposal 3, titanium roof and mesh wood cover

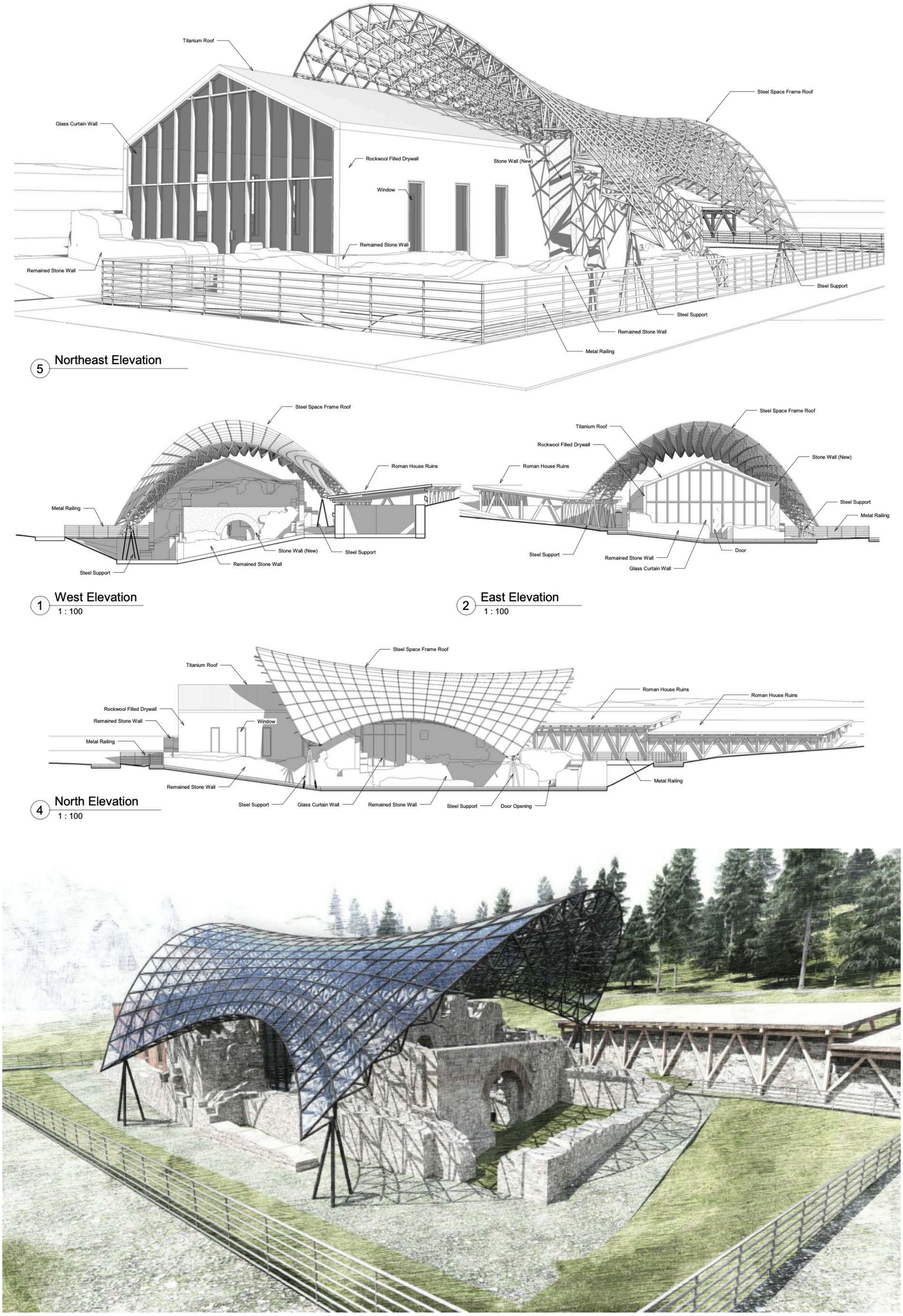

Figure 4.27. Restoration proposal 4, glass cover

Due to the dilapidated state of the building and its location in the archaeological area, the idea of preserving the current state of the restoration approach and constructing only a protective roof for this purpose was welcomed by the experts of both countries. One of the alternatives prepared due to the negotiations was not chosen, but the approach was appreciated. A new model was prepared in line with the feedback received (Figure 4.28).

Figure 4.28. Approved restoration proposal, 3D view

The visuals prepared to express this approach have achieved their purpose. At first, using the software to model the current situation seemed like a colossal waste of time. However, as can be seen from the restoration alternatives prepared for the building, 3D documents were obtained with Revit to meet the expectations (Figure 4.29-b and Figure 4.35).

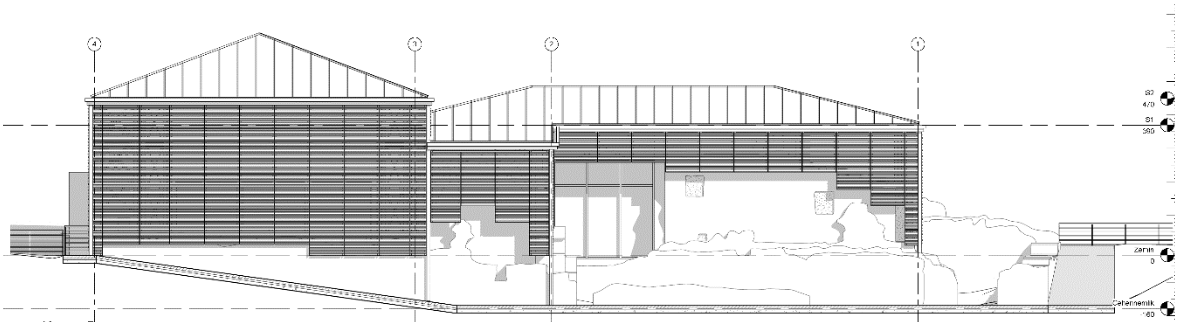

Figure 4.29. Restoration proposal, elevation

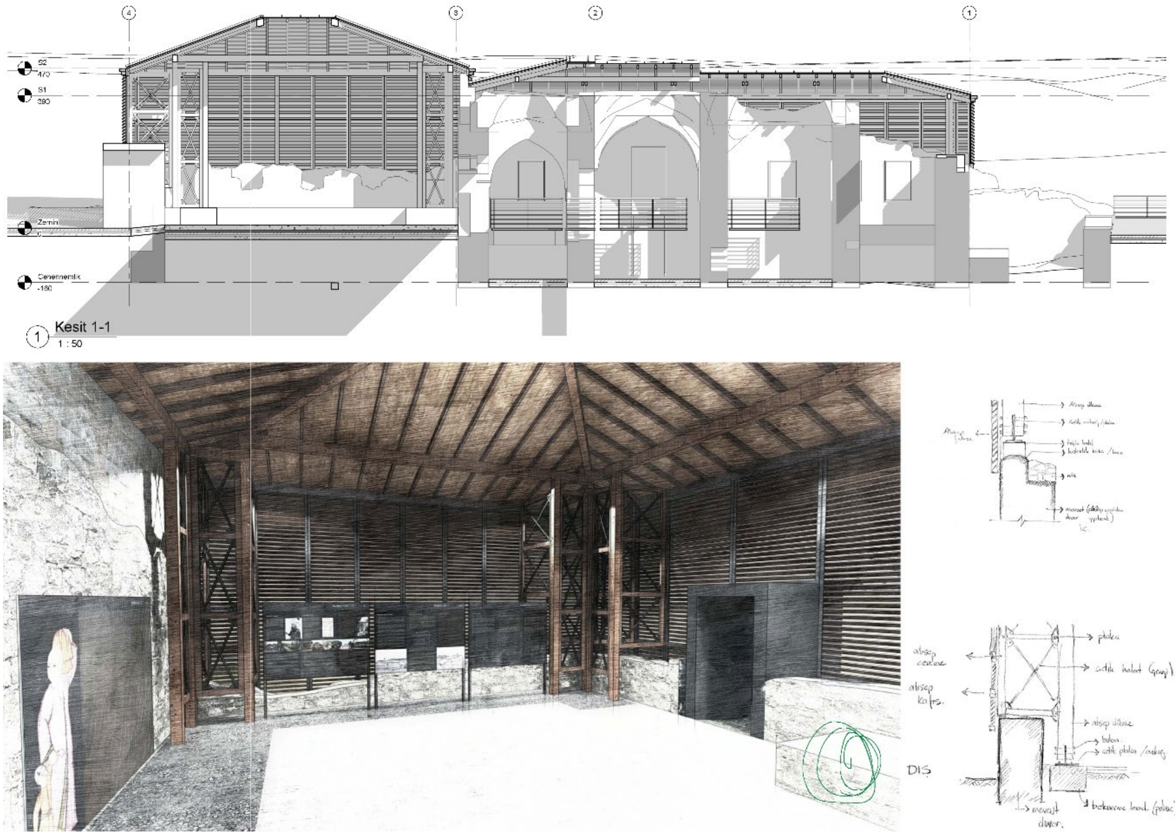

Figure 4.30. (a) Section, (b) interior perspective, both prepared with Revit

Model 2D documents produced with the Revit model are very promising. Although the parts showing the current situation are insufficient, the display of the new annexes was deemed sufficient according to the criteria of the technical documentation (Figure 4.29-a, Figure 4.29).

The model prepared with Revit has also been successfully used to produce 3D interior images planned to transform into a museum. The *soğukluk*, which is the most significant part of the building designed as a museum, has been transformed into a space that exhibits the building and its purpose (Figure 4.30-a). The model has been prepared not only for 3D presentation (Figure 4.28), but also for technical purposes such as producing bills of materials. Parametric libraries have been designed for all productions and preparations have been made for any revisions that may be requested. In particular, the total load (weight) amount can be easily calculated with Revit lists so the dimension of the carriers can be determined as a result of static calculations. Thus, the model has become an essential advantage for static analyses.

Consolidation and annex

The model produced for the preparation of the restoration projects of the building was found insufficient for the production of 2D documents. This result cannot be said to be a surprise. As it is known, BIM software wants to standardize products to reduce errors. But each element of heritage buildings should be considered unique. In this structure, modeling damaged-missing objects are pretty tricky. Since this result was estimated, survey and analytical survey drawings were prepared with the classical method to fulfill the contract requirements.

Identifying the problems of the building and showing them on the analytical survey is the first technical step (Section 4.3.2). Solution suggestions should be made for each of these problems, and these suggestions should be shown on the report and drawings using the mapping method.

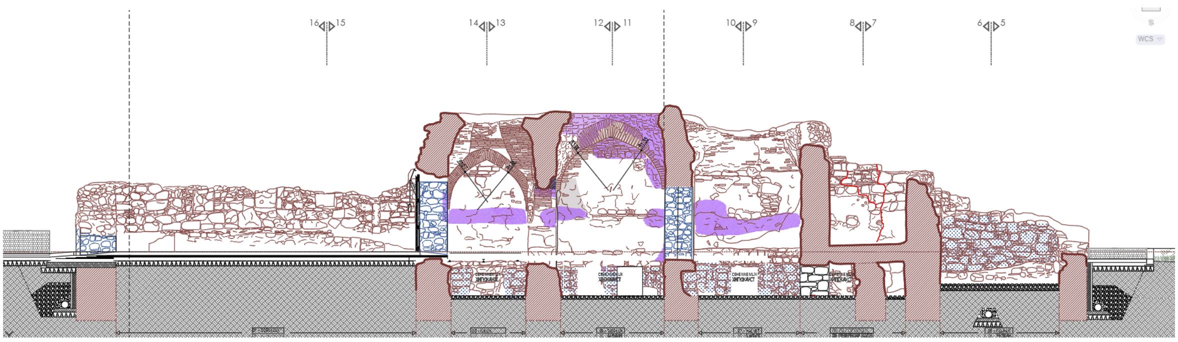

Figure 4.31. Consolidation drawings

Since the survey and analytical survey were prepared with AutoCAD, the interventions were prepared in the same environment (Figure 4.31). Therefore, interventions, such as reductions in the masonry, cracks in the masonry structure, cleaning and joint/plasterwork to be done after removing unqualified additions, are shown in all drawings.

Drawings prepared for consolidation are not presented alone. New additions should also be shown in the exact drawings. As can be seen in Figure 4.33, consolidation and annex should be shown on a single drawing but legible. Thus, all project stakeholders will clearly understand what has been removed, what has been preserved and strengthened, and what has been newly added.

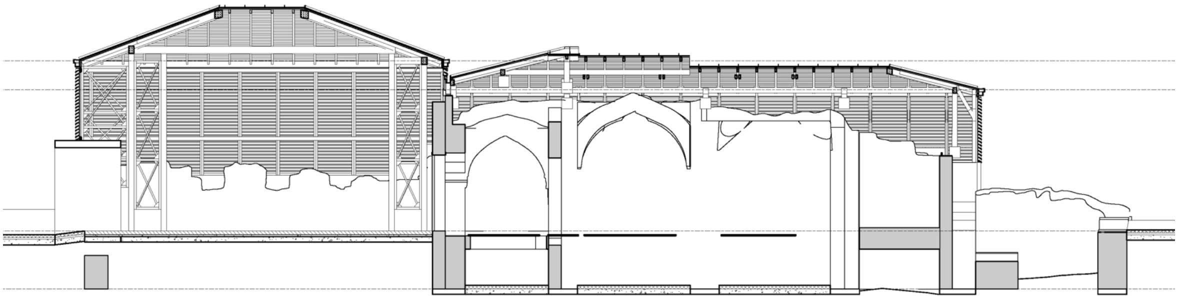

Figure 4.32. Section generated in Revit

Revit's success in producing 2D documents was evaluated and it was decided that it failed to represent the structure's existing parts (Figure 5.1). The success of the suggestions prepared with Revit in three dimensions is also observed in the production of 2D execution drawings (Figure 4.32). This section has been exported as DXF. The main idea is to filter out the parts showing new additions and combine this file with the consolidation drawings produced with AutoCAD. Parts showing the building's current state acted as masks and new additions were successfully separated. Thus, the following drawing is obtained by combining Figure 4.31 and Figure 4.32.

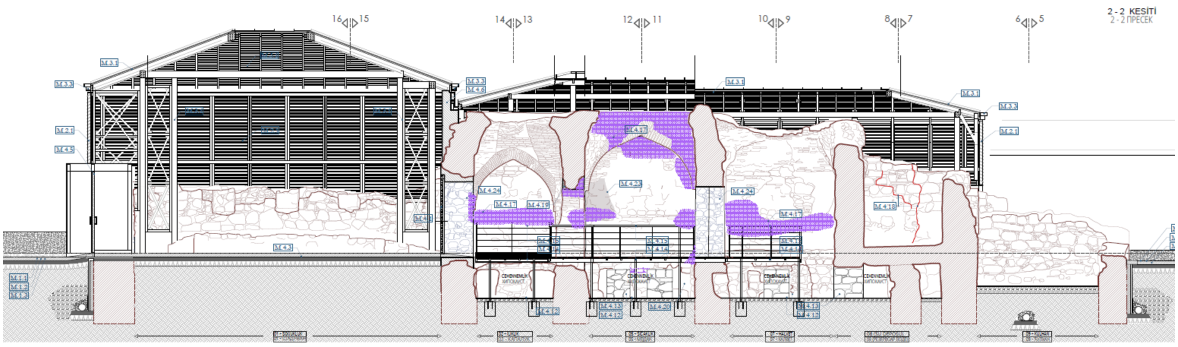

Figure 4.33. Section of restoration project, intervention

Existing parts are shown in color and annex are shown in black in the drawing. Thus, a document that meets the specification requirements is obtained.
Transferring 2D drawings (consolidation) produced with AutoCAD to Revit and creating documents through Revit can be used. However, this method is not wise, as the desired image will still be 2D. On the contrary, drawings corresponding to all plans, sections and views produced with AutoCAD were prepared with Revit, exported in DXF format and merged in AutoCAD (Figure 4.34). Merge is configured as Xref, not copy and paste. With

this method, any changes made with Revit can easily and automatically be transferred to the drawings. In addition, Xref provides a clean user interface and robust layer control.

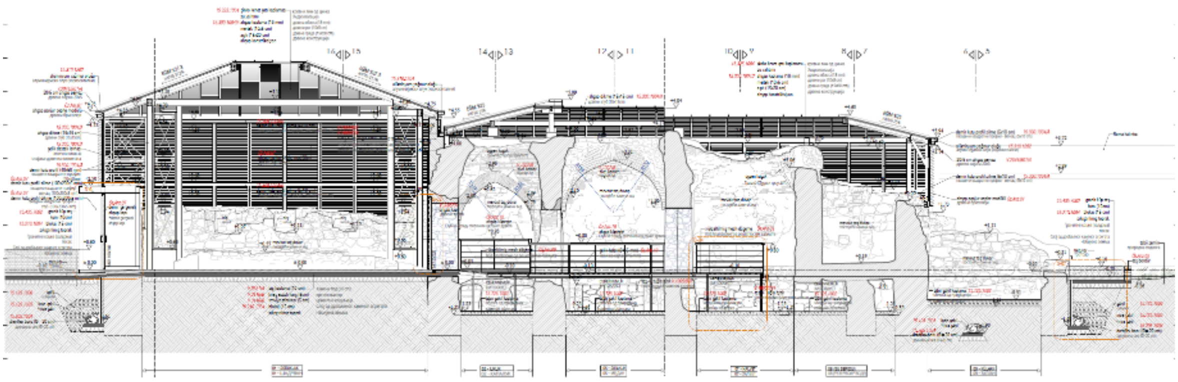

Figure 4.34. Combined drawings of the restoration project

Explaining the prepared restoration proposal from different perspectives strengthened the expression in the technical documents (Figure 4.35).

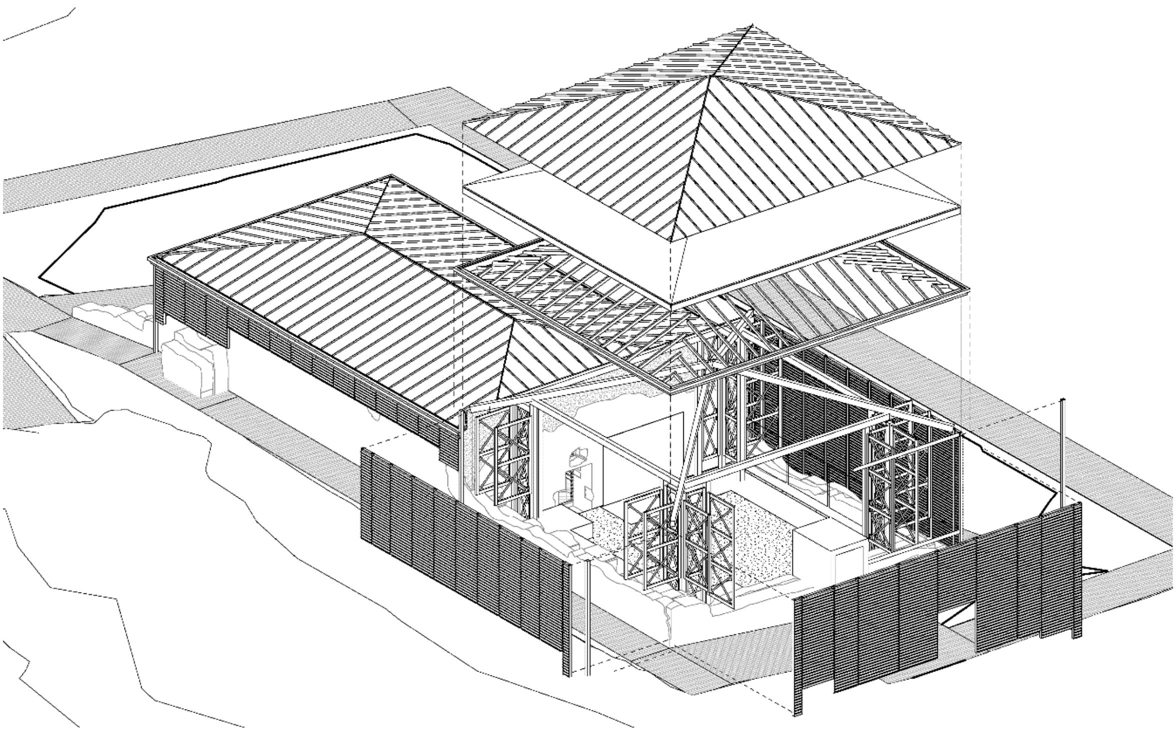

Figure 4.35. Restoration proposal produced by Revit, used displacement tool

4.5. Structural Model and Analysis

In this section, examining the static behavior of the current state of the building, the creation of two models and cooperation with Revit are discussed. The first of the models were made to analyze the building's current state. The second model is for the annex in the restoration project.

4.5.1. Current situation analysis and data transfer

According to the classical first workflow, the survey must be completed to create the static model. In this structure, the structure's static behavior was determined by making a voxel model (Aydoğmuş, 2019) instead of the classical Finite element model (FEM) (Barazzetti *et al.*, 2015). There are two reasons for choosing this method. The first is the difficulty in generating suitably simplified static diagrams due to the lack of flat surfaces on the structure. The second reason is the use of different materials in the wall construction. Due to the inhomogeneous material distribution, it is difficult to determine the values to calculate wall strengths. In addition, the building's historical nature makes it difficult to carry out strength tests by taking samples. Non-destructive tests, on the other hand, do not yield results that can determine the structure's mechanical behavior.

The building model was created in SAP2000 software. In line with the available data, survey studies, on-site investigations and engineering experience, the structural system that forms the building geometry is reflected in the analysis model and structural system analyses of the building have been carried out. In addition, it was investigated whether the structural sections of the structure modeled in SAP2000 are sufficient.

It was impossible to share the produced Revit model to prepare a static model. The classical FEM method is generally used to examine the building's current state. This model combines surfaces with nodes and loads are transferred via nodes (Abbate, Invernizzi, and Spano, 2020). The produced model could not be used for static analysis due to the fragmented state of the objects and the lack of contact of the connection points in the produced Revit model.

A method known as voxel model was used to model the structure. The structure was modeled using point cloud data. The advantage of this method is that it can create a carrier system from cube-shaped building elements that can better represent the building (Bitelli *et al.*, 2018).

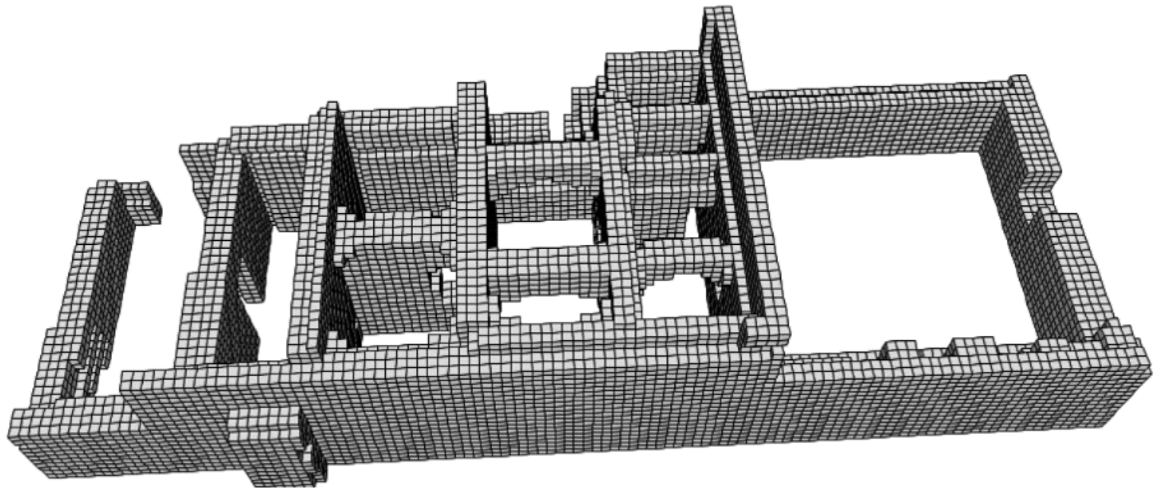

Figure 4.36. Voxel model, SAP2000

The secondary aim of the experiments with Rhinoceros at the architectural as-found state model stage was to produce the voxel model. (Figure 4.20). The polyline generated using the point cloud for Rhino could be used for both jobs. With the help of the areas obtained from the point cloud with 25cm sections, 25cm cubes were created, and the solid model closest to the actual geometry of the structure was obtained. The building model developed for the Mahmud Pasha Hammam consists of 27,034 solid elements (Figure 4.36). Thus, a suitable model was obtained for the anomalies, missing parts and ruins in the wall structure of the building. For Rhino, the sections created at 25cm intervals were insufficient; the polyline produced at 12.5cm intervals was used. This available data could create a static model, but potent hardware was needed because the final model was so heavy. Thus, it was decided to use 25cm cubes.

4.5.2. Annex and data exchange

There are two roofs in the proposed restoration project. Both shelters are made of wooden structures. The first of the tops (the *soğukluk* roof) will transfer the load to the ground, while the existing stone walls will carry the warm section’s roof (Figure 4.37). Both structures are parametrically designed and exported with Revit.

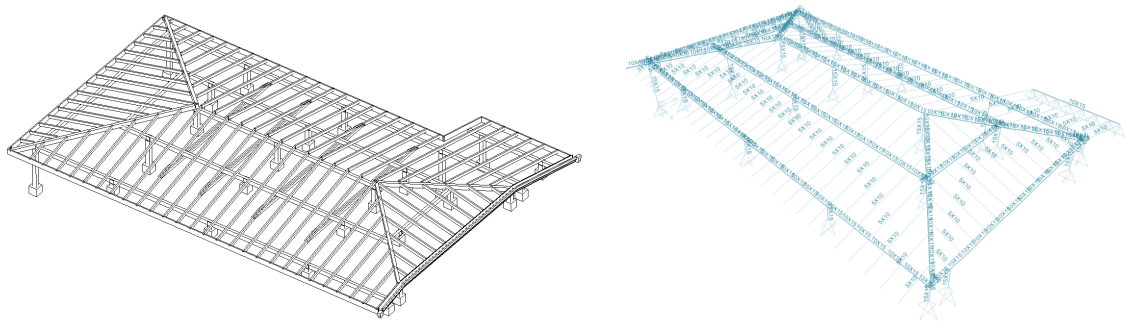

Figure 4.37. *Sıcaklık* roof, (a) Revit model, (b) SAP2000 model

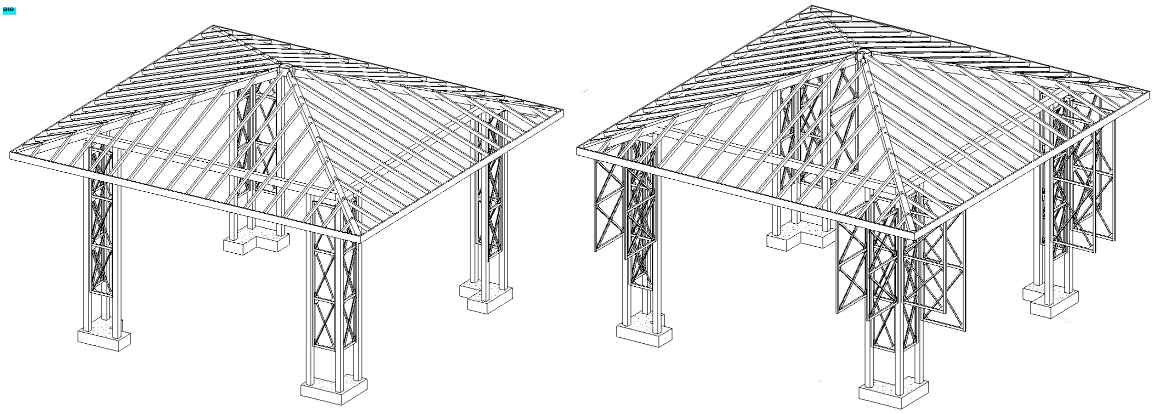

Figure 4.38. *Soğukluk* roof structure exported from Revit, (a) Roof structure only, (b) Structure with side carriers

In the cold part, the roof form is not entirely square, fits inside the existing walls and requires a unique design. Since the structure will not be hidden and used for aesthetic/symbolic purposes in architecture, it was designed with Revit under the architectural discipline with static predictions (Figure 4.38). The positions and numbers of the carriers are essential in the produced model. The structure was designed and exported using node-dependent structural elements from the libraries offered by Revit so it does not need to be remodeled in static software. The model was successfully imported to SAP2000 with few exceptions (Figure 4.39-a).

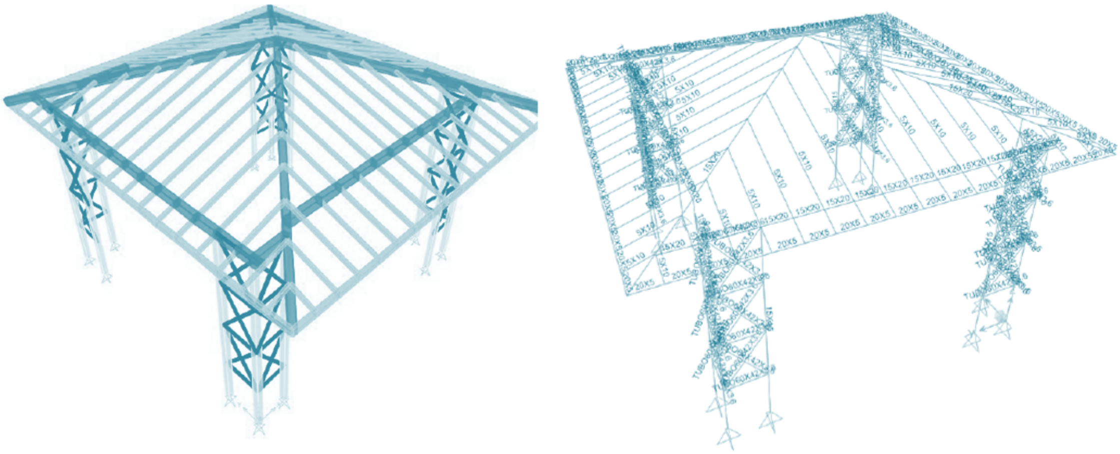

Figure 4.39. Structural frame of main (*soğukluk*) roof, (a) 3D view in SAP2000, (b) framed view in SAP2000

The carrier sections of the roof designed with Revit were determined approximately (with foresight) while the architectural project was being prepared. The sections determined as a result of the calculations can be seen in Figure 4.39-b.

In the Revit model, the net spacing in the three-pillar wooden structure used at the corners was 60cm. After static calculation, it was concluded this interval should be 75cm. Since the library consisting of box profiles and braces designed between wooden uprights designed with Revit is parametric, it can be easily adapted to new values. Sections of the box profile, which form the frame of the wooden columns and the crosses used as the cross between the columns, were also adapted to the sections obtained as a result of the calculations.

5. DISCUSSION

Seven goals were set to achieve the aim of the study. The results of five of them have been discussed in this chapter. The objectives to be assessed in this section are briefly:

- Usability of Scan to BIM manual data processing
- Information exchange and data sharing with structural model
- HBIM-based visualization among the stakeholders
- Organizational improvements and accurate cost estimation
- Documentation in a collaborative manner for speedy project execution

5.1. Scan to BIM Manual Data Processing

The most significant share of studies on HBIM in the literature belongs to modeling. Just as Revit's native tools are used, the model-in-place tool is also used a lot. Of course, although it is possible to use tools such as Dynamo to produce parametric models, hesitations and reservations are expressed about expressing cultural assets with parametric objects (Scianna *et al.*, 2020). Another approach is to import surfaces created using utilities into the Revit environment. In particular, automatic/semi-automatic production of mesh surfaces from a point cloud, creating NURBS surfaces with Rhino, and importing them into the BIM environment are frequently preferred applications. It is possible to use point cloud directly or 2D drawings to model the as-found state. In addition, only BIM tools can be used or a model can be obtained by using different auxiliary software. Revit built-in tools were used in this study by attaching point cloud to the Revit environment.

It took a lot of effort to get a survey model with Revit. The first method that comes to mind is modeling the wall with the wall module, the floor with the slab, and the roof with the roof module. The first results were obtained without going too far. Due to the pre-defined relations of components such as walls, floors and roofs, control problems were experienced during the creation of existing structures. If any of the multiple walls converging in a node is moved, the other walls are also affected and their position changes. While it is a handy feature when designing a new structure, it posed a problem for the study subject. Although automatic control of the joins can be turned off, the inability to issue this command in bulk (each node must be selected separately) has made control difficult, presenting an error-prone workflow. The second trial was made with the mass modeling tool – a model was obtained with the model-in-place (mass model) tool. Although it is possible to be more flexible in the model made using the model-in-place tool, a consensus text was needed for classification compared to the standard tools. For example, are the domes and vaults of the structure acceptable as a roof or can arches be acceptable as beams? Such questions need to be answered (Figure 4.15 and Figure 5.1-a). Each user's approach may be different; thus, the classification differences may undermine the model's reliability.

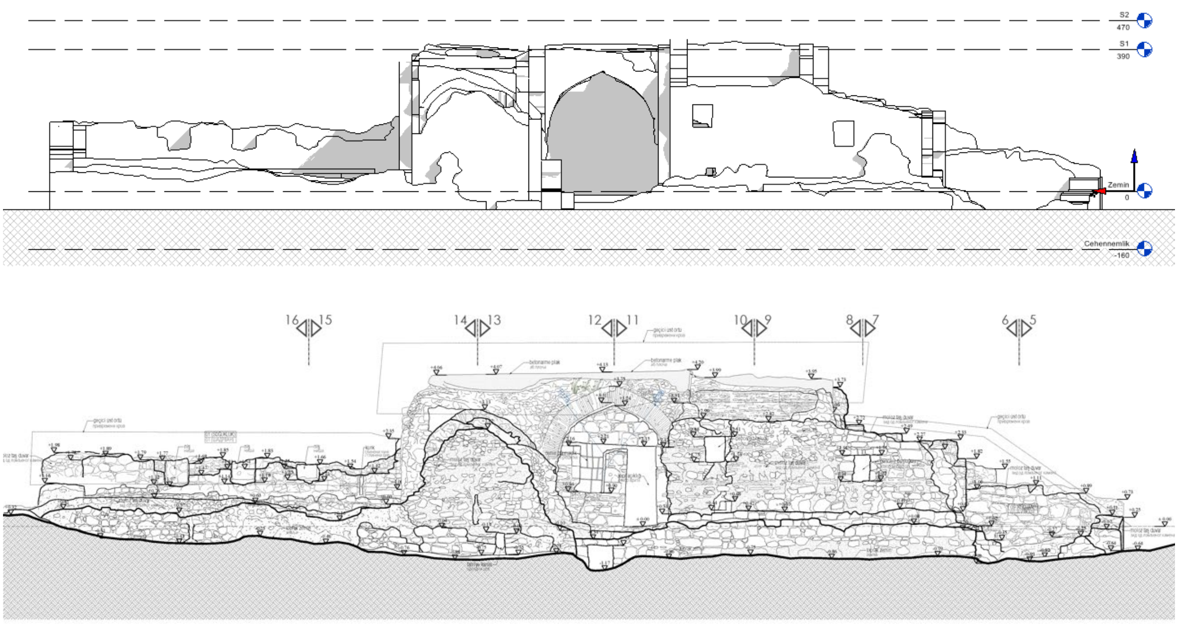

Figure 5.1. Comparison of elevation, (a) Revit elevation, (b) AutoCAD elevation

Although the two-dimensional documents produced from the model can give an idea about the form of the structure as they are not sufficient for execution purposes, the Revit model was not used for processing the problems. Issues and deterioration analyses prepared by the specification were made with AutoCAD in two dimensions (Figure 5.2).

Previous studies mentioned that if structures with no smooth surfaces cannot be modeled faithfully, success can be achieved by using orthophotos dressed on BIM software tools; thus, a lighter model can be obtained without causing data loss (Adami *et al.*, 2017). Suppose the documents to be produced on the accepted model were only appearances. In that case, this hypothesis might be accurate, but the issue of the authenticity of the information and documents to be produced on the solid model, such as plans, sections and even the bill of materials, remains an unsolved problem.

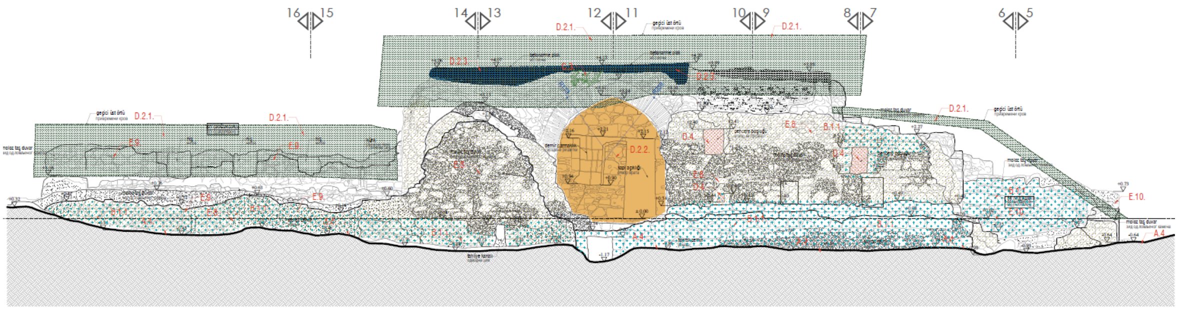

Figure 5.2. Processing of decay into 2D drawings

Even with successfully obtaining the survey model with Revit, it is tough to transfer the problems to the model, according to the research in the literature (Tsilimantou, Delegou, Nikitakos, Ioannidis, and Moropoulou, 2020). A few suggested methods can be grouped:

1. 2D preparation with traditional methods and transfer to BIM software (Tsilimantou *et al.*, 2020)
2. Processing as surface paint on BIM (Malinverni, Mariano, Di Stefano, Petetta, and Onori, 2019)
3. Developing a surface-based library (Acampa, Grasso, and Iop, 2020)
4. Transferring NURBS surfaces to BIM environment via different software (Brumana *et al.*, 2017)

The proposed methods are quite laborious and inefficient compared to the classical method. In their work Lo Turco, Mattone, and Rinaudo (2017) say the model should be simplified to add problems and it can be accepted if it does not contradict the purpose. But the BIM model must be produced to serve many purposes. The purpose of the model being parametric was that it could be shared and updated for many purposes in the first place.

Revit can display a point cloud, but not the flexibility of AutoCAD (Figure 4.11). It is necessary to navigate through the menus to change, close or color a point cloud cluster that contains many sessions and does not offer comfortable use.

It was known from the very beginning that modeling heritage buildings with standards-based BIM software are a challenging process (Adami *et al.*, 2017). When we use software for other than its intended purpose, opposing sides arise, and it is necessary to manipulate the software to eliminate them.

To achieve success, it is not enough to produce 2D documents only with the model. It is important that distortions can also be displayed. As a result, one of the important purposes of documenting the as-found state situation is to detect deteriorations as a basis for restoration work.

Modeling tools can give successful results in structures with simple surfaces. Modeling complex structures is troublesome. The situation in this structure is a little more complicated. This building is not entirely standing. The wall coverings of the building have almost wholly disappeared. Although the upper cover is a dome, all the domes have been destroyed.

5.2. Data Exchange for Structural Analysis

Two static models of the structure were made. The first of these is the current situation analysis. The second is the static calculation model of new add-ons. The path followed for both stages was differentiated and a separate evaluation was made.

5.2.1. Sharing the as-found state model

Only statics were considered to share the model with other disciplines, and mechanical and electrical disciplines were excluded. However, there was no success in sharing the Revit model to obtain a static model. This situation can be examined under two headings:

1. Node points are needed for the FEM. However, it was produced with Revit as-found state model mass model. Information on this subject is given in Section 5.1. Since the building components created with the mass model do not have axes and nodal points, the exported model remained a cult and could not be transferred to the static model.
2. Voxel, one of the FEM model techniques, is the analytical model that has been found suitable for the structure. Surfaces and nodes were created with the help of cubes. Could these volumes be created from the Revit model? It is difficult to answer yes to that. A

clean model could not be obtained in the Revit model due to the intermingled masses. At this point, the use of point cloud, which is more accessible, was preferred due to the tightness of the budget. As explained in section 5.1, since the Revit as-state model was not successful, the point cloud was sliced at regular intervals to create NURBS surfaces with Rhino. This data was used for voxel model production, the work was not lost, but data sharing with Revit remained inefficient.

5.2.2. Sharing proposed restoration model

It is essential that a very complex model has been/can be created for static calculations in terms of time management and cost. The proposed canopy consists of many different sizes and components. This means a significant workforce requirement for the creation of the static model.

The carrier elements of the shell designed for the building were constructed using the structural objects provided by the Revit software. Each carrier's connection point (node) is associated with being exported for the static model. The model called into the SAP2000 software could not be used due to the inability to connect a few elements, but a generally usable model was obtained.

The benefits of data transfer can be summarized under two points:

1. Time is saved as the model does not have to be rebuilt. Although it is not possible to give precise periods here, a time saving of two weeks can be mentioned.
2. Since the source is the architectural model and the location or number of carriers does not change as a result of static calculations, the necessity of overlapping the static model with the architectural model is eliminated. The carrier sections have changed and new areas have been quickly processed into the Revit model. Although the lack of changes resulted in project progress and the scarcity of revisions, there was a gap in the research results since it was not necessary to include the static model in the Revit environment and no comment was made on this issue.

5.3. Visualization

The model, which was prepared to represent the current state of the building, could not be used for technical drawings. At the same time, it could not be shared to make static analyses. However, the Revit model can give an idea about the building's current state and can be used for visualization. It has been concluded this model can be used in restoration alternatives and exhibition arrangement projects and can be used for visualization.

Observed but not compared with exact criteria, the benefits of visualization with Revit can be listed as:

- Concept projects could be developed quickly and with a relatively more minor workforce.
- The bill of materials for each proposal was prepared automatically to give an idea about its rough cost.
- In a multinational environment, many restoration proposals and alternatives have been prepared, and a sense of satisfaction has been created in stakeholders regarding what can be done.
- The 3D alternatives have accelerated the decision-making process of non-technical stakeholders.
- In a multinational project, misunderstandings that may arise between people who speak different languages were prevented. The assurance that the restoration approach was expressed correctly and the stakeholders (parties) understood it increased the confidence in the results of the negotiations.
- The fact that each of the proposals was capable of going into the implementation phase allowed the design team to increase their self-confidence and continue the dedication made to the project.

5.4. Cost Estimation

The advantage of evaluating the restoration project in three stages has provided significant benefits in preparing the approximate cost. The effect of the three stages on the approximate cost is explained below the items:

1. The building's current state was evaluated by making historical data and material analysis, and it was recommended to remove unqualified interventions such as the protection roof and concrete coating. The cost was not a factor in carrying out these works because they are a necessity in terms of restoration theory.
2. The necessity of the works revealed after the removal of unqualified parts and proposed in the section to be conserved was not a matter of discussion. Among these items, works were aimed at improving the building's current condition, such as moss removal and plaster repairs.
3. Shell design and functional add-ons for museum construction were evaluated in the third section and many alternatives were prepared. At this stage, the approximate cost of each proposed alternative is considered. The cost of proposals was an essential criterion for the decision-making process.

Although manual calculations were made to prepare the approximate costs of the works in the first two stages of the restoration project, these works were not repeated. The reason for this is that the problems seen in the existing structure remain constant throughout the project. For this reason, it is thought the use of BIM in the works done to show the distortions and eliminate these distortions will increase the time spent on the model instead of reducing the workload.

The building is in Serbia, but since the project and implementation belong to the Turkish side, where to get the materials to be used has been the subject of discussion due to several parameters such as durability and controllability. As far as we know, the strength of timber in Serbia is at the lower limit. In this case, it is necessary to change the timber according to the approximate cost calculations. Thus, if the approximate cost of the structure exceeds the budget, the focus will be on the use of local lumber to save on transportation. In this case, since the timber has poor strength, its cross-section will change (grow) and all drawings will have to be changed. As the timber cross-sections grow, the amount of timber will increase and the price may rise again. In this case, timber will be procured from different geography by transportation. As can be seen, among the factors that change each other, presentations should be made to decision-makers in the light of precise data and they should be expected to make decisions. Final projects should be completed depending on these decisions. BIM technologies have provided significant benefits in making such decisions.

5.5. Documentation

2D documents obtained with the survey model are not usable, as shown in Figure 5.1. This is because the structure is in a dilapidated state; that is, it has almost no flat surfaces, and at the same time, BIM software does not offer the appropriate tools to model such irregular structures. But with the separation of the workflow into existing and annex or new additions, the software was finally able to do its job. Revit tools were used directly to design new attachments and satisfactory results were obtained (Figure 5.3).

Even if the structure is small, many drawings must be made to describe the structure due to its organic surfaces. Sections should be passed through each space, and care should be taken not to leave any invisible surface in the building. In addition, the technique and approach used in the soğukluk and sıcaklık roofs differ, and the structure proposed in both sections contains small parts. As it can be understood, it is challenging to express this suggestion with classical methods. The Revit model has made it very easy to express this fragmented situation. It has made it possible to obtain technical drawings that enable the proposal to be presented in 2D and 3D, thus strengthening communication.

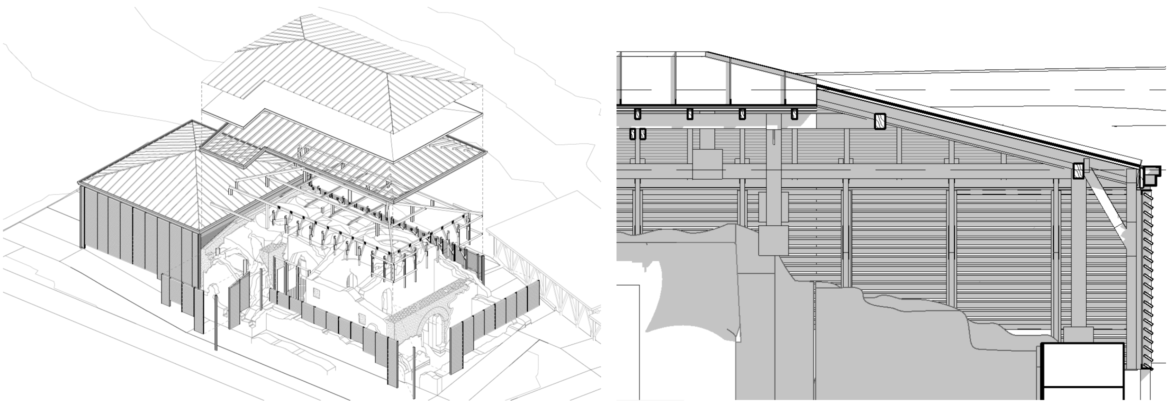

Figure 5.3. (a) Roof displacement 3D view, section, (b) Same place 2D drawing exported to AutoCAD

Sixteen sections, six plans and four views were created in the building to obtain the restoration execution project (Figure 5.4). With the easy transfer of 2D DWG drawings from the restoration proposal model, the final drawings were quickly obtained. During the project, many models were tested and the drawings exported from these models were combined with the Xref method. Although this process was repeated many times, no signs of fatigue were observed in the project team. Revision requests are unsettling under normal circumstances. Within the scope of this study, no uneasiness was observed even when revisions were requested at dimensions that would require static analysis.

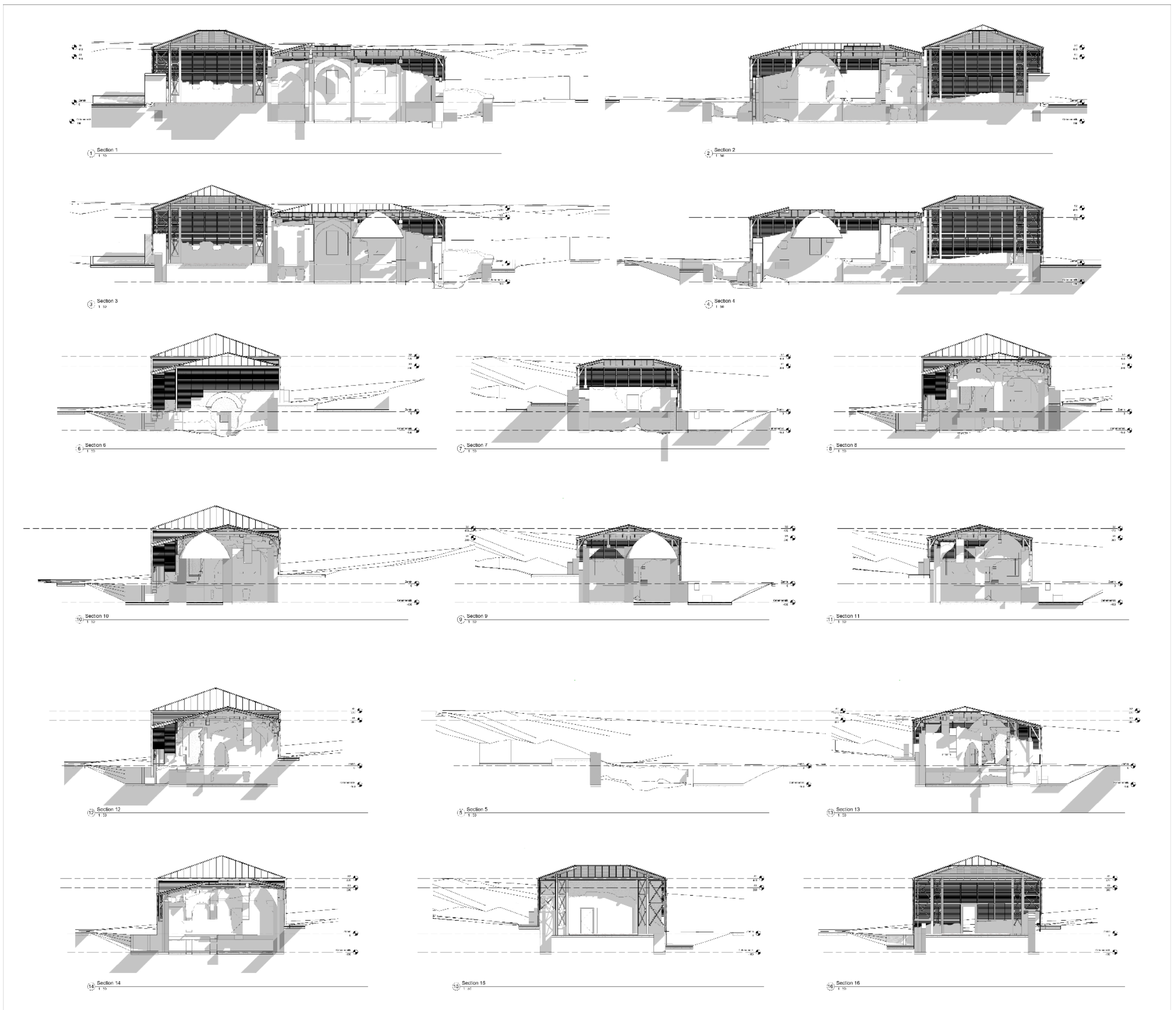

Figure 5.4. All sections (16) produced by Revit

6. CONCLUSIONS AND FUTURE REMARKS

The main purpose of the BIM application, which is proposed to replace the traditional methods used for the protection of CH, is to provide the common database platform necessary for decision-making activities by ensuring the information produced collectively by all actors involved in the protection-repair process is always kept up-to-date and shared. The main motivations for this change effort are: the inefficient workflow observed in traditional 2D document-based systems; delays in knowledge generation and sharing; problems experienced in the representation of the building and the expression of restoration proposals; the magnitude of the effort made to keep the data produced consistent; *etc*. In the HBIM adaptation studies carried out in the last ten years, it has been emphasized the available tools are not sufficient. Considering the fact the main reason for the problems reported in the HBIM studies is the tool-purpose mismatch and considering the fact the existing technology is designed for new construction processes, that hypothesis has been developed: “in order for the BIM technologies and approach to be effective in architectural CH projects, there is a need for a new workflow in which existing software can be used for its purposes.”

To investigate the extent to which BIM can be used in projects prepared for architectural CH and test the hypothesis, Mahmud Pasha Hamam, which is a professional work within the scope of the contract, was chosen. Each of the projects to be prepared under the contract was prepared in 2D with AutoCAD and simultaneously with Revit.

In this study, the current state of the building was determined by laser scanning, the survey drawings and model were created, the structural condition of the building was analyzed, the deteriorations were determined and restoration proposals were prepared. The as-found state includes two phases: survey drawing/model and analytical survey drawings. The restoration project includes three phases: demolition project (scope of the restitution project), conservation/consolidation of the remaining and new additions (annex). These five items could only be prepared with the as-found state model and annex Revit, while the other three items were completed with AutoCAD (Figure 6.1). The data obtained were evaluated as 2D documents, sharing the model with other disciplines, cost estimation and visualization.

Table 6.1. CAD-BIM comparison in the context of project process and outcomes

			OUTCOMES				ON THE PROCESS				
			2D Documentation	Data sharing	Visualization	Cost Estimation	Precision	Delivery Process	Speed	Qualified Personel	Hardware Req.
As-found state & analysis	Surveyed drawing	BIM	-	-	+	-	-	-	-	-	-
		CAD	+	+	NA	+	+	+	-	+	+
	Analytical drawing	BIM	NA	NA	NA	NA	NA	NA	NA	NA	NA
		CAD	+	+	NA	+	+	+	+	+	+
Restoration Project	Demolition plans	BIM	NA	NA	NA	NA	NA	NA	NA	NA	NA
		CAD	+	+	NA	+	+	+	+	+	+
	Conservation consolidation	BIM	NA	NA	NA	NA	NA	NA	NA	NA	NA
		CAD	+	+	NA	+	+	+	+	+	+
	New additions	BIM	+	+	+	+	+	-	+	+	-
		CAD	+	+	NA	-	+	+	+	+	+

Table 6.1 shows the works done in this study under the headings of survey and restoration. In each process, the data obtained with CAD and BIM were evaluated. According to the results, the as-found state model could only be used for visualization purposes. However, the annex part of the restoration phase was completely made with Revit and positive results were obtained. The structure was evaluated in two parts, showing the improvements/ interventions to be made to its current state and additions; the current situation was made with classical methods (AutoCAD), additions were made with Revit, and 2D documents were produced over a dynamic structure by combining the data obtained from the two platforms with the Xref tool in the AutoCAD environment. Thus, an efficient workflow was created by combining the good sides of each method in one project (Figure 6.1).

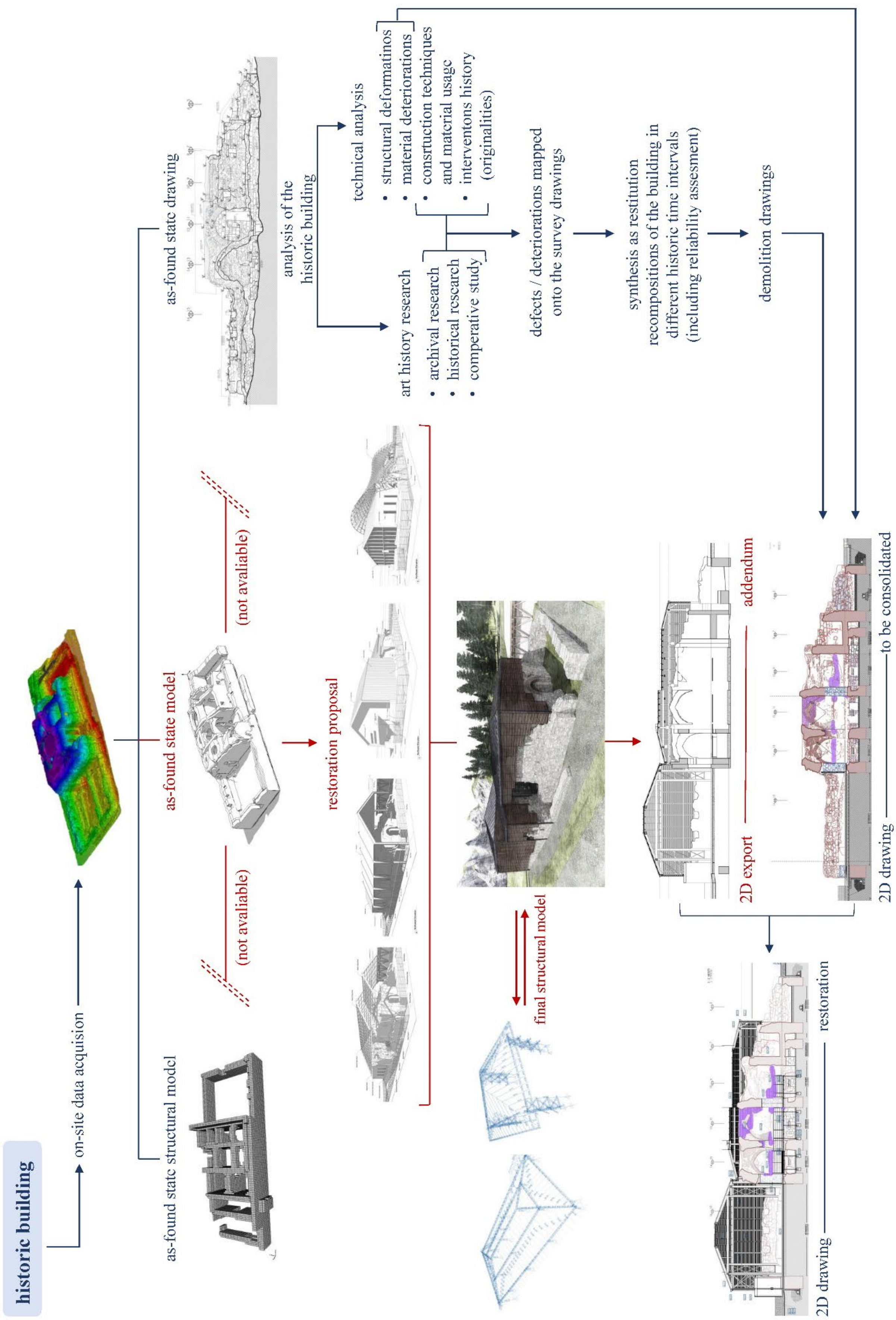

Figure 6.1. Proposed workflow for BIM and CAD integration

The following benefits have been achieved with the workflow developed for integrating BIM technologies with classical methods in historical monument projects:

1. With the model prepared for the restoration proposal, interdisciplinary data transfer was made and speed was gained. Since the source and target platform are the same, the necessity of performing conflict analyses due to data transfer has been eliminated, and a consistent and reliable model has been obtained.
2. Restoration alternatives could be obtained quickly and relatively easily. In a multinational project where experts from different disciplines were involved, the language problem was eliminated, and accurate and effective communication was ensured.
3. In preparing restoration alternatives, in the preparation of the project execution papers, creating the approximate cost and the decision-making processes of the product supply, speed and convenience have been achieved.
4. The time allocated for the preparation and evaluation of different restoration alternatives has decreased, many alternative restoration proposals have been prepared and satisfaction has been achieved among stakeholders.
5. Preparation of construction drawings includes strict processes. The resulting workflow provided speed and consistency in the stages of visualization, cost analysis, data transfer and obtaining construction drawings.
6. As a result of the division of the work into parts considering the software's capabilities, each workgroup working in the survey and restoration gained the ability to work simultaneously, and the existing labor could be used more efficiently.
7. During the development of alternatives, it was observed that the repetitive work was considerably reduced compared to the classical methods, and the mental/emotional fatigue that may arise from the revisions was prevented in the work team.
8. The flexibility achieved through the integrated workflow gave the project stakeholders an idea about how BIM technologies can be used in historical artifact projects and awareness/awareness was created. This was considered a significant success for the dissemination of HBIM.

6.1. Limitations

The most important limitation of the study is that the BIM model is not requested with the contract and technical specifications. Therefore, the work is mainly focused on the production of 2D documents; all outputs are delivered as DWG, PDF and printed documents. Important issues such as IFC data transfer and semantic development of the model remained outside the scope of the study. Since the model could not be delivered, data on its efficiency and usability in the construction process could not be obtained.

Another important limit concerns the case study chosen. There are no original elements on the building, such as doors and windows, that would require the creation of parametric libraries. While modeling the traces of the dome and vaults, their original state was taken into account and relatively parametric objects were created, but this experience was very limited. Therefore, experience with BIM software and as-found state model is limited to model-in place tool only. Of course, many libraries have been created and used for the annex part, but it is already known that the software is quite skillful in this regard.

Since a successful survey model could not be obtained with Revit (Table 6.1), a trial was conducted only with Rhinoceros, which is another method that can produce free forms such as mesh/NURBS, which is common in the literature. Although the heterogeneous and amorphous surfaces of the structure are a significant challenge, different trials could not be made due to the lack of experience of the existing workforce to try different software combinations, the license fees not included in the budget and the limited time. Since the model produced with Rhino was not considered sufficient by the project team, it was not included in Revit, and the experience of interaction between software was very limited.

Demonstrating deterioration is among the most problematic issues in the HBIM study area. Different approaches have been tried in the studies on this subject, but only the surface deteriorations have been sampled in the selected structures. In this study, the issue of how to show the deteriorations is out of scope since the structure chosen does not have flat surfaces and the Revit model is not sufficient.

6.2. Future Work

HBIM studies are still very new and the lack of international standards for modeling heritage buildings undermines the modeling's consistency. Although undamaged detection systems can be used, especially for the invisible parts of a historical artifact, there is a possibility that different layers may emerge. In BIM technologies, it is not possible to transfer possibilities such as the thickness, quality or existence of the material to the CH model. The assumption that every piece of information entered into the model is precise and the approach of different users to the subject directly affects the quality of the model (Colucci *et al.*, 2020). Various attitudes in model generation and transferring semantic data of objects to the model can cause problems in sharing, archiving or updating the HBIM model. Since the modeling approach, tools used and results obtained differ in each study, the results of the literature research also support this view. As a result, the HBIM model, which aims to create a common platform by enriching the building components with semantic data and thus enabling the easier transfer of information, suffers from a lack of standards.

The lack of demand for BIM technologies is considered the biggest obstacle to HBIM (Banfi, 2017). Demand drives development. Although benefits have been obtained by using the technique up to a point, the fact the customer does not contractually request the BIM model causes some problems; that effort is wasted, vehicles are not developed, the model cannot be delivered and it is out of date. Thus, it ceases to be an appropriate tool to document the whole process of heritage buildings. According to the protection theory, all control and monitoring activities should be documented and retained as part of the building history (ICOMOS, 2003). While BIM tools are not currently adequate for the entire protection process, they can be efficient for specific purposes. Thus, increasing awareness and demand can accelerate the development of tools.

Since BIM tools are designed for new construction processes, modeling the built environment has difficulties. However, restitution studies aim to show the undamaged condition of the building in specific periods. In addition, since the restitution is not an application project, the precision of the measurements can be stretched a little. It is thought that the phasing modeling tool offered by Revit software may be suitable for restitution studies. Especially the models of restitution proposals attract people's cultural interest.

Visualizations in this area can be successful. Thus, a contribution is made to the inclusion of society in the conservation processes.

6.3. Conclusion

BIM technologies that can be used at present, even when modeling the built environment or the building, direct the model to the ideal state of the building as if it were new. It can be said the building does not have the ability to fully represent its current state. It has been shown in this study that existing BIM technologies can be beneficial when used for their purposes. The fact that most of the studies in the literature are built on a BIM model in which damage and deterioration are not processed, and the emergence of inefficient processes in a small number of studies for modeling deterioration confirms the hypothesis of this study.

Although the demands for consistency and sharing of information are similar regardless of the type of building, in practice there are great differences between the production process of the new building and the preservation of the historical heritage. For this reason, BIM systems are not yet efficient and reliable for managing protection repair processes, with a few exceptions such as restitution and asset management.

Awareness needs to increase in order for BIM technologies to be used. Although there is no BIM expectation within the scope of the Mahmud Pasha Hammam project contract, the gains obtained with the use of BIM can create awareness that can reveal new possibilities. Thus, contributing to the consideration of alternatives during the preparation of specifications for future projects creates an opportunity for all actors involved in the project to gain new ideas.

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