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Research Article

The Heritage Building Information Modelling of the Church of St. Sophia in Ohrid, North Macedonia

Ramazan Alper Kuçak [1*], Adalet Dervİşoğlu [2]

[1] Assistant professor, Doctor, Department of Geomatics Engineering, Faculty of Civil Engineering, Istanbul Technical University, Istanbul, Türkiye
[2] Assistant professor, Doctor, Department of Geomatics Engineering, Faculty of Civil Engineering, Istanbul Technical University, Istanbul, Türkiye
* **Corresponding Author:** kucak15@itu.edu.tr

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ABSTRACT

Building Information Modelling (BIM) has emerged as a major topic in sectors connected to building in recent years. It's possible to think of this technology as a procedure, a certain kind of database, software, or even a 3D model, but in reality, it merges all of these functions and many more. The geometry of a structure is represented using parametric objects with attribute data through BIM. Adopting BIM in the heritage area is challenging because of the parametric limitations of the current software's incapacity to adjust to the morphological flaws common in historical systems. A standard for heritage artifacts is the Heritage (Historic) Building Information Modelling (HBIM). In addition to enabling the storage of geographical data and metadata, it also offers a way to record changes these structures go through. The range of applications ranges from straightforward documentation repositories to building and restoration simulation systems. The Hagia Sophia Church chosen for this study was built in 1506 in the Republic of North Macedonia and is on the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage List. The Church, scanned with 3D terrestrial laser scanning technology by CyArk, was modelled and analyzed using many programs (CloudCompare and Autodesk REVIT) for HBIM. After analyzing object details measured by a laser scanner, the HBIM models of the church were generated. With this study, it has been shown on which surfaces the open source CloudCompare program can be used on HBIM models and that the Autodesk REVIT program is a suitable tool for HBIM modeling studies.

Keywords: Cultural Heritage, Church of St. Sophia, Laser Scanning, HBIM.

INTRODUCTION

Heritage is our legacy from the past, what we live with today, and what we pass on to future generations. Our cultural and natural heritage are both irreplaceable sources of life and inspiration (UNESCO, n.d. b). The United Nations Educational, Scientific and Cultural Organization (UNESCO), with the "Convention on the Protection of the World Cultural and Natural Heritage" dated 16 November 1972, is responsible for the protection and promotion of natural areas, cultural structures and traditional elements that have survived from the past to the present and are accepted as the common heritage of humanity. By 2022, there are World Heritage sites in 167 countries, the World Heritage Convention has been ratified by 194 countries and there are currently 1,154 sites on UNESCO's World Heritage List. UNESCO World Heritage Sites are divided into the following main categories: Cultural Heritage Sites (897), Natural Heritage Sites (218) and Mixed Heritage Sites (39). It also exists in areas defined as "transboundary areas (43)" (areas between the territories of two or more countries) (UNESCO, 2023). Cultural heritage refers to individual monuments such as architectural works, monumental sculptures, and paintings, as well as buildings and sites when considering areas containing archaeological sites according to the World Heritage Convention (UNESCO, n.d. a). According to the expanded definition, it is now possible to include regional systems, landscapes, routes, and intangible heritage in characterizing cultural heritage (Ferretti, Bottero, & Mondini, 2014). Countries that have signed the Convention Concerning the Protection of the World Cultural and Natural Heritage apply to UNESCO Tentative Lists for properties that they consider outstanding universal value as cultural and natural heritage and, therefore, suitable for inclusion on the World Heritage List. Eighty-two properties from Türkiye are included as candidates in the lists submitted by the 186 countries that are party to the agreement (UNESCO, n.d. c). The decision as to whether a candidate property is eligible for inclusion on the UNESCO World Heritage List is a complex, multi-step process involving a variety of stakeholders.

Cultural heritages provide information about the historical development stages of humanity, and thus, their functions are important in the objective development of historical consciousness and in establishing a healthy cause-effect relationship regarding the past. The past lives of all communities in the world form the pieces of a puzzle that complete each other in human history (Rukancı, 2018). For this reason, cultural heritage is a universal value rather than a concept that belongs to only one country and stays within that country's borders (Batmaz & Biçici, 2021). The destructive effects of natural disasters such as earthquakes, fires, tsunamis, and floods worldwide are especially seen in residential areas and cause great material and moral losses. Among these losses, cultural heritage is the most essential value that is almost impossible to replace after human life. The damage and destruction created by humans on cultural heritages are more significant than that produced by nature. Throughout history, wars, terrorist incidents, and looting have had more devastating effects than natural disasters (Karpuz, 1990). Cultural heritage protection is a multifaceted field encompassing a wide range of studies and research efforts to preserve and safeguard the world's cultural heritage. Important studies and initiatives in this field can be grouped into several key areas, including archaeological research, conservation and restoration, law and policy, cultural anthropology, and digital technologies. Archaeological studies play an essential role in transferring cultural heritage to future generations by preserving the traces of the past. The conservation and restoration of cultural heritage involves a combination of scientific, technical, and ethical considerations to ensure the longevity and authenticity of cultural heritage. Law and policy play a critical role in protecting and preserving cultural heritage. They provide a framework for the legal and ethical treatment of cultural heritage assets, ensure their safeguarding, and address issues related to ownership, repatriation, and international cooperation. Cultural anthropology studies human societies and cultures and is essential to understanding, preserving, and appreciating cultural heritage. Digital technologies have become indispensable tools for protecting, preserving, and promoting cultural heritage. They offer innovative solutions for documenting, conserving, and making heritage accessible to a broader audience. The studies carried out to protect the assets of cultural heritage and transfer them to the next generation with all their features are gaining importance and accelerating all over the world day by day (Pieraccini, Guidi, & Atzeni, 2001; Kuçak, 2013; Altuntas, Yildiz, & Baygul, 2014; Liritzis, Al-Otaib, & Volonakis, 2015; Borowiecki, Forbes, & Fresa, 2016; Kaimaris, 2018; Kuçak, Kiliç, & Kisa, 2016; Altuntas, Hezer, & Kirli, 2017; Salama, Ali, & El-Shiekh, 2017; Skublewska-Paszkowska, Milosz, Powroznik, & Lukasik, 2022; Panagiotidis & Zacharias,2022; Psalti et al., 2022; Psarros, Stamatopoulos, & Anagnostopoulos, 2022; Sertalp, Emmez, Bütün, Doğan, & Büyükkarakaya, 2023). Determining the current situation is the first step in protecting and recording these values. Geoinformatics technologies, including photogrammetry, Terrestrial Laser Scanning (TLS), remote sensing, web mapping, and geospatial data science, have long played an essential role in documenting and protecting cultural heritage (Xiao et al., 2018). 3D modeling and digital archiving are extremely important in identifying, monitoring, preserving and restoring cultural heritage artifacts. TLS is a measurement system for quickly and efficiently gathering 3D data spread across a vast region (Kuçak et al., 2016; Kuçak, Erol, & Işiler 2020). According to the traditional measurement methods, 3D more precision and dense point clouds may be created using the TLS system's power and accuracy. Therefore, technologies such as TLS are frequently preferred because they can obtain fast and detailed data in obtaining 3D data.

Building Information Modelling (BIM) is primarily a 3D digital representation of a structure or a building with its intrinsic characteristics. BIM is primarily a 3D digital representation of a structure or a building with its intrinsic characteristics. BIM is a combination of procedures, database software, and 3D models. BIM involves a set of standardized procedures and methodologies for creating and managing building information. These procedures guide how information is collected, stored, and shared throughout the entire lifecycle of a project. BIM procedures include protocols for data exchange, collaboration, and quality control. BIM relies on specialized database software that allows stakeholders to store, organize, and access data in a structured and interconnected manner. This software is used to create a centralized repository of information related to the project, making it accessible to all relevant parties. BIM software often includes features for 3D modeling, data visualization, and collaboration. 3D modeling is a fundamental component of BIM. It involves creating detailed, three-dimensional representations of a building or infrastructure project. These models not only include the physical geometry of the structure but also embed a wealth of information about its components, materials, systems, and more. This 3D modeling aspect helps in visualizing the project, simulating its behavior, and identifying potential issues before construction begins.

BIM is of great interest in the fields of archaeology, architecture and cultural heritage. Historic or Heritage BIM (HBIM) is the term used for BIM technology in the 3D digitization of ancient historical structures HBIM is an essential and intelligent tool in cultural heritage management, as it provides the documentary basis for any subsequent work and project creation on these assets for current and future maintenance, conservation and restoration purposes (Murphy, McGovern, & Pavia, 2009; Rocha, Mateus, Fernández, & Ferreira, 2020). The geometry of a structure is represented using parametric objects with attribute data (Alshawabkeh et al., 2021). The specification of the Level of Detail (LoD), which in HBIM differs from the LoD assigned to a new building model, must be set a priori. LoD solely concerns the geometrical representation of the modelled elements in HBIM and BIM, not their semantic meaning. Depending on the goals and potential uses for which the model was developed (Scianna, Gaglio, & La Guardia, 2020). Choosing an acceptable LoD for an HBIM model is difficult since it involves sculpting architectural elements so they are not over or under-represented in contrast to real items (Aricò & Brutto, 2022). The most thorough method of segmentation and modelling in HBIM representation is still manual, although it is a time and resource-consuming operation. Implementing HBIM can have different difficulty levels, depending on several factors, including the complexity of the heritage asset, the data available, the goals of the project, and the expertise of the team involved. Here are some of the challenges and difficulties that can be associated with HBIM:

1. The processing of complex data must be done without mistakes, discrepancies or unplanned data loss.

2. Point cloud files are enormous.

3. This process cannot be completed by a single piece of software, and the lack of connectivity between multiple types of software used for different tasks can compromise the outcome.

4. All of which call for strong machines, knowledgeable personnel, and an established process (Aricò & Brutto, 2022).

The point cloud can be used as an essential component for numerous methodologies that can be used to create parametric or 3D models. To build parametric surfaces, form classification algorithms are employed in the majority of automated operations; numerous research studies have used the Random Sample Consensus (RANSAC) method (Croce et al., 2021; Kucak, 2022a). According to Fischler and Bolles (1981), the Random Sample Consensus (RANSAC) approach extracts forms by creating candidate shape primitives by selecting random minimum data points. A classification is also carried out if the primitives have any semantic significance (Schnabel, Degener, & Klein, 2009; Grilli, Menna, & Remondino, 2017). In a 3D point cloud, the RANSAC algorithm looks for basic forms like cones, spheres, cylinders, and torus. It recovers primitive forms from point cloud data by randomly choosing minimum groups of points and fitting primitive shapes (Kuçak, 2022b).

St. Sophia Church in Figure 1 (Trekzone, n.d.), located on the shores of Lake Ohrid in the Republic of North Macedonia and included in the UNESCO World Heritage List, was built in 1056 during the Byzantine Period. (Kurt & Alaydin, 2015). It reflects the diversity of religious life people have developed in the region for over a thousand years. From its foundation mortar to its heavy roof, it highlights a region ruled by the Roman, Byzantine and Ottoman empires for centuries. Built on the ruins of a fifth-century Roman church, the structure was destroyed and rebuilt many times using the same elements. The church walls are covered with fresco murals with subtle Byzantine influences. The building was converted into a mosque by the Ottoman Empire in the 15th century, with the plastering of the frescoes and adding minarets to the north chapel (Open Heritage 3D, n.d. a).

Figure 1. The Church of St. Sophia

CyArk is a nonprofit organization founded in California, United States, in 2003. CyArk's mission is to digitally record, archive and share the world's most significant cultural heritage and ensure that these places continue to inspire wonder and curiosity for decades to come (CyARK, n.d.). CyArk has pioneered the application of 3D recording technologies for the preservation and celebration of cultural heritage and worked with local partners at more than 200 facilities in more than 40 countries. They share data online to facilitate broad reuse for education, research and other non-commercial purposes and to unlock its full potential.

St. Sophia Church was documented by CyArk in September 2018. CyArk captured further high-definition images of the inside frescoes while documenting the church's interior and outside (Trekzone, n.d.).

In the study, the church of St. Sophia Church, whose data was provided by CyArk, was selected to create HBIM models. The data was downloaded from the “Open Heritage 3d.org” site (Open Heritage 3D, n.d. b). This site is an open data site that includes cultural heritage data from all over the World. There is no study in which HBIM methods are applied using this church. The study was conducted to reveal the use of HBIM in cultural heritage studies. It aims to contribute to HBIM studies by showing the advantages and disadvantages of commercial and non-commercial open-source software and algorithms in the use of HBIM by using two programs such as Revit and Cloudcompare with RANSAC Algorithm. Therefore, HBIM studies were applied to a selected area of this church with Autodesk REVIT and CloudCompare programs. When the resulting models are compared, many superior aspects of the Autodesk REVIT program are seen. Also, it has been shown that some HBIM studies can be done with the RANSAC algorithm with the open-source program Cloud Compare.

DATA AND METHODOLOGY

Terrestrial Laser Scanner Data

LiDAR (Light Detection and Ranging), whether airborne or terrestrial, is one of the technical methods that allows for collecting enormous amounts of 3D data in a short period. It generates a point cloud with intensity values in the local coordinate system; internal or external digital cameras often supply extra information, such as RGB values (Kuçak et al., 2016; Kuçak, Özdemir, & Erol, 2017).

A Terrestrial Laser Scanner (TLS) is a type of measurement system used for capturing highly detailed three-dimensional data of objects, structures, or landscapes from the ground level. It uses laser beams to measure distances between the instrument and the target, allowing for the creation of accurate and detailed point cloud data. Terrestrial laser scanners are commonly used in various fields, including architecture, archaeology, engineering, forestry, geology, and cultural heritage preservation.

TLS is a measurement system for quickly and efficiently gathering 3D data spread across a vast region (Kuçak et al., 2016; Kuçak et al., 2020). Lasers, carefully calibrated receivers, timing, ultrafast micro-controlled motors, and precise mirrors make up TLSs (Fowler & Kadatskiy, 2011). The virtual point cloud created by all the 3D points from the surfaces scanned in synchrony is the fundamental data gained from each scan. According to the traditional measurement methods, 3D more precision and dense point clouds may be created using the TLS system's power and accuracy.

HBIM

HBIM stands for "Historic Building Information Modeling." It refers to the use of BIM technology in the context of historic or heritage buildings, sites, and structures. HBIM involves creating digital models and representations of historic structures and incorporating relevant data to aid in documenting, conserving, restoring, and managing these cultural heritage assets.

Many historic buildings have irregular geometries, non-standard construction techniques, and unique architectural features. These complexities may not align well with the standardization that parametric modeling or modeling programs often require. HBIM goes beyond traditional architectural and engineering documentation methods by utilizing 3D modeling and digital data to capture the unique characteristics, materials, and historical significance of heritage buildings. This approach allows for more accurate preservation efforts, better decision-making, and improved communication among stakeholders involved in the preservation and management of historic sites. The geometry of a structure is represented using parametric objects with attribute data through BIM. Adopting BIM in the heritage area is challenging because of the parametric limitations of the current software's incapacity to adjust to the morphological flaws common in historical systems (Alshawabkeh, Baik, & Miky, 2021). The accuracy of parametric modeling depends heavily on the quality and completeness of data. Historical structures may have missing or inconsistent data, making it challenging to create precise parametric models. The use of parametric modeling can sometimes lead to excessively complex models, which can be difficult to manage and interpret, especially for smaller heritage sites with limited resources. Historical or Heritage BIM (HBIM) is the term for using BIM technology to 3D digitalize old historical structures (Murphy, McGovern, & Pavia, 2013). As it offers the documentary foundation for any subsequent study and project creation regarding those assets for present and future care, preservation, and restoration objectives, HBIM is an essential and intelligent instrument in the managing cultural heritage (Rocha et al., 2020).

Methodology

The process steps of HBIM modeling are given in Figure 2. Data Collection and Research consist of collecting historical and existing data through methods like laser scanning, photogrammetry, and surveys. The second step is to create a 3D Model. In this step, a 3D digital model of the historic structure or site is generated using the collected data. Also, this step includes accurate representations of geometry, dimensions, and unique architectural features and incorporates historical and cultural data into the 3D model, such as construction techniques, historical significance, and original purposes. The third step is Analysis and Restoration. In this step, experts analyze the HBIM model to assess its historical and architectural significance and test different scenarios and restoration approaches virtually to understand potential outcomes. Then, the HBIM method guides restoration projects by simulating proposed changes and interventions. Finally, the last step is Documentation. In this step, changes to the HBIM model over time, including restoration activities and maintenance, were documented, and maintained a historical record of interventions and alterations.

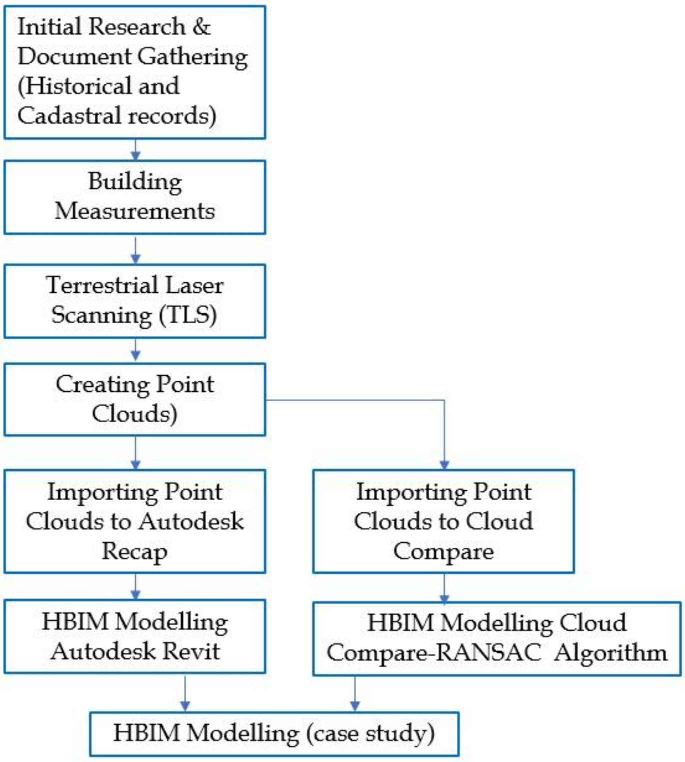


Figure 2. The Steps in an HBIM Flowchart

Autodesk Revit follows standardized building practices, which may not align well with irregular geometries or unconventional materials often found in historic structures. This can make it challenging to accurately represent these elements. There are heritage-specific BIM solutions such as ArchiCAD Heritage or Vectorworks Architect with heritage add-ons. These may have features designed specifically for historical preservation. In some cases, custom software or scripting can be developed to address the unique requirements of a specific heritage structure. This approach offers the highest level of flexibility. HBIM modeling with RANSAC Algorithm in Cloud Compare can be given as an example of such situations. However, the RANSAC algorithm cannot be an alternative to REVIT. Open-source BIM software like BlenderBIM or FreeCAD is an alternative to proprietary solutions like Autodesk Revit. They provide flexibility and can be tailored to specific project needs. Also, Software such as Faro Scene or Leica Cyclone can be used in conjunction with laser scanning to capture highly detailed point clouds. These point clouds can then be imported into various BIM software applications for modeling.

APPLICATION

TLS

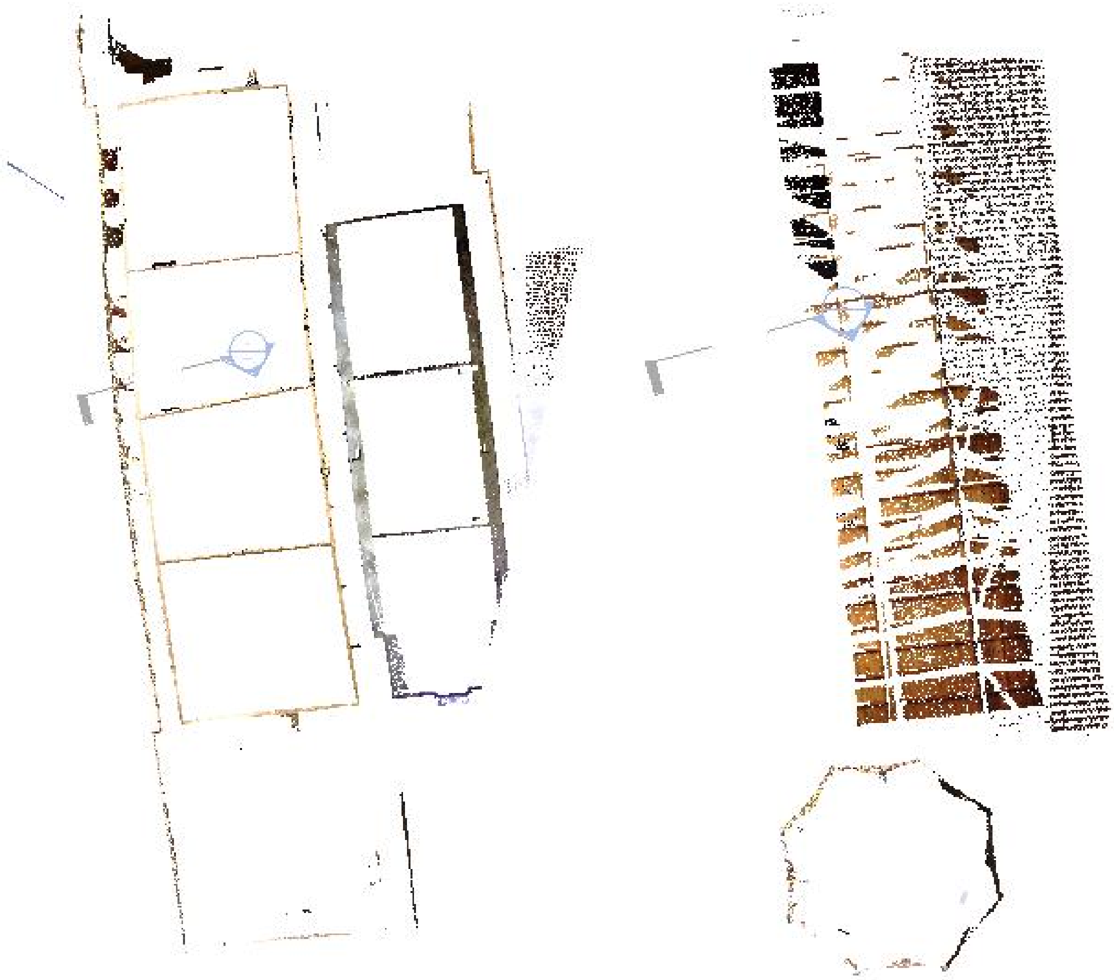
The church was documented by CyARK with a Faro Focus S350 laser scanner. Only terrestrial laser scanner data were used in this case study. Faro Focus S350 is phase based laser scanner and is widely used in various fields, including architecture, engineering, construction, cartography, and cultural heritage preservation (FARO, n.d.). The Faro Focus Laser Scanner is used mainly for high-precision 3D scanning. It captures millions of data points in minutes, creating detailed and accurate 3D point clouds of objects, buildings, or landscapes. It measures approximately 1 million points per second, and the 3D point position accuracy is 2 mm at 10 meters and 3.5 mm at 25 meters. This scanner is known for its extended range of capabilities, making it suitable for scanning large structures, archaeological sites, and expansive environments. The scanner can perform on-site data processing, which means that you can check the quality and completeness of scans in the field, saving time and ensuring you have the data you need. It is designed to be used both indoors and outdoors, making it versatile for various scanning environments. It provides real-time visual feedback, allowing users to view the scan data as it is being acquired, which helps ensure the coverage and quality of scans. The scanner can capture color information, which is useful for capturing texture and appearance in addition to geometry. It is typically compatible with various software applications for processing, analyzing, and visualizing the 3D scan data. On the other hand, While the Faro Focus S350 provides highly accurate data, further developments in automation and real-time data processing could improve efficiency in the field. Also, environmental factors, such as adverse weather or poor lighting conditions, can impact the scanner's performance. As a result, Faro focus S350 is a terrestrial laser scanner that can be preferred for HBIM studies, thanks to its accuracy and detailed point cloud.

Figure 3. TLS Data

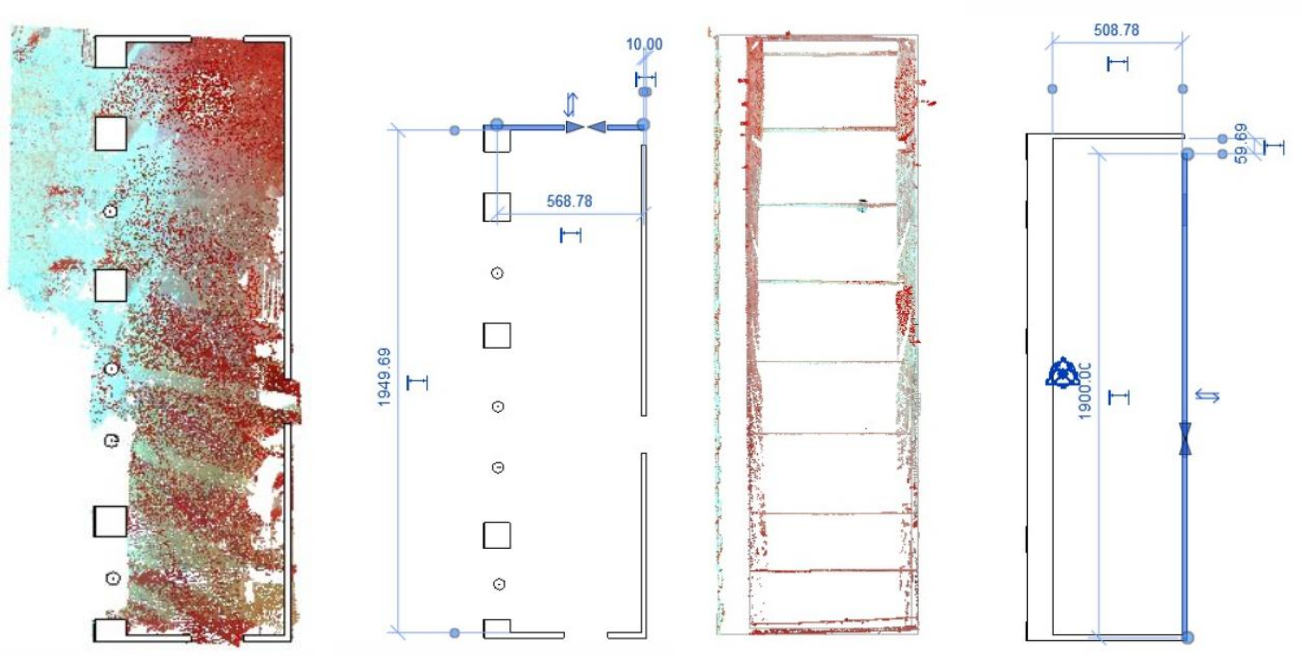
HBIM Models

Figure 4 shows the columns and walls obtained automatically in the CloudCompare program with the Ransac algorithm. Figure 5 shows the roof and attic plans obtained with the Autodesk REVIT program. The ground and first-floor plans are given in Figure 5b. Figure 6a shows the point cloud data of the working area in the Coud compare environment, and Figure 6b shows the HBIM model produced with Autodesk REVIT from the 1st-floor point cloud.

Figure 4. CloudCompare HBIM Models for Columns with RANSAC Algorithm



(a)



(b)

Figure 5. Autodesk REVIT Floor(a) and Roof Plans(b) for HBIM

(a)

(b)

Figure 6. CloudCompare Point Cloud Model (a) and Autodesk REVIT HBIM Model (b)

It was observed that the HBIM models obtained above can be obtained very quickly with the Autodesk REVIT program (Figures 5 and 6). The HBIM models obtained in Figures 5 and 6 could be obtained very quickly with the Autodesk REVIT program. On the other hand, no surface except a few walls and columns (Figure 4) could be obtained automatically with the RANSAC algorithm of the CloudCompare program. While architectural columns can be drawn automatically quickly with Autodesk REVIT with REVIT's library, only straight columns can be drawn automatically with the RANSAC algorithm. RANSAC, by design, seeks to find a "best fit" model for a set of points. In the context of historical structures, this can lead to oversimplified models that do not capture the intricate details and irregularities of the building accurately. In some cases, custom algorithms or scripting can be developed to model a specific heritage structure. This approach offers the highest level of flexibility. However, the RANSAC algorithm cannot be an alternative to Autodesk REVIT software. RANSAC is primarily focused on geometric modeling. It may not effectively capture other aspects of heritage structures, such as materials, historical inscriptions, or decorative elements. Therefore, To mitigate these limitations, it's essential to approach RANSAC-based modeling with a critical eye and an understanding of its strengths and weaknesses. Using RANSAC as a part of a broader modeling approach that combines various data processing techniques, and expert knowledge of the historical context can help address these challenges and ensure the accurate representation of heritage structures in HBIM modeling.

However, it is observed that 3D drawings can be made on walls and desired surfaces with both programs, and it is observed that more professional 3D drawings and HBIM models can be made with Autocad REVIT. On the other hand, REVIT Family Editor does not support the input of point cloud files in standard formats (Rocha et al., 2020). Thus, to put it in the family editor, the points relating to the objects to be modeled must be separated and exported in different formats (dxf, ply). This technique was carried out by using CloudCompare. Another problem was that by default, doors, walls and columns in REVIT are modelled with a rectangular or plane surface insertion cut; however, especially in traditional buildings, every detail is formed by combining many arched structures. Because of this condition, standard families cannot be used, and new ones must analysing be created that employ different columns or doors. This is a good example of using the CloudCompare program with REVIT. These results have shown on which surfaces the open-source CloudCompare program can be used for future studies on HBIM models and that the Autodesk REVIT program is a suitable tool for HBIM modelling studies. With this study, it has been demonstrated that different restoration approaches, revealed by HBIM models in the restoration of historical monuments, can be quickly produced in virtual environments to evaluate historical and architectural importance.

DISCUSION AND CONCLUSION

Studies in various fields continue worldwide to transfer, protect, and sustainably manage cultural heritage for future generations. One of the most important of these studies is Digital Documentation and Preservation. Studies are carried out on advanced digital technologies such as 3D scanning, photogrammetry, and digital archiving to document and protect cultural artifacts and sites accurately. Building Information Modeling (BIM) is a digital documentation and management system that has applications in various fields, including documenting and preserving cultural heritage. HBIM, "Historic Building Information Modelling," is a specialized application of BIM technology and methodologies to document, preserve, and manage historical and cultural heritage buildings and sites. HBIM creates digital representations of historic structures and their surroundings, allowing architectural and construction information to be documented accurately and in detail. HBIM empowers specialists to comprehend, record, and safeguard historical structures, simultaneously providing accessibility for researchers, students, and the general public. This technology facilitates the delicate equilibrium between preserving the integrity of historical buildings and ensuring their ongoing utilization and significance in today's society.

To create HBIM models for this case study, the church of St. Sophia Church, whose data was given by CyArk, was used. The information was obtained from the website "Open Heritage 3d.org". This website contains open data about cultural assets from around the globe. Therefore, HBIM investigations were done on a particular portion of this church using the Autodesk REVIT and CloudCompare tools. When the final models are compared, it is seen that the Autodesk REVIT software has many more excellent features. Additionally, it was demonstrated that various HBIM investigations may be carried out using the RANSAC algorithm using the free software CloudCompare.

The results show on which surfaces the open-source CloudCompare program can be used and that the Autodesk REVIT Program is suitable for HBIM modeling studies. The study guides future studies on HBIM models. It should be remembered that practical algorithms and programs must be selected according to the user's needs and data type. In the context of HBIM, it is essential to carefully consider the specific needs and characteristics of the heritage structure when choosing the most appropriate software and methodology. Depending on the needs of the project, an alternative method or software solution may be more effective than or an alternative to Autodesk Revit, especially when dealing with the unique challenges of historic structures While parametric modeling is flexible, it may not always capture the unique characteristics of historical structures. For instance, modeling decorative stonework or ornate details can be challenging in Revit. Historical data may not always align seamlessly with Revit's data structure. Specialized fields for historical data integration may be needed. In some cases, scripts and algorithms such as RANSAC can be developed to address the unique requirements of a specific heritage structure. This approach offers the highest level of flexibility. However, RANSAC-based modeling often requires manual intervention and post-processing to refine the results. This can be time-consuming and may require expertise in point cloud processing. RANSAC is primarily focused on geometric modeling. It may not effectively capture other aspects of heritage structures, such as materials, historical inscriptions, or decorative elements. Therefore, The findings may highlight the need for standardized procedures, guidelines, and protocols specifically tailored to HBIM for heritage structures. Future research can focus on the development of such standards to ensure consistency and interoperability.

Essentially, HBIM offers the benefits of modern technology with the preservation of historical significance, ensuring that heritage buildings and areas are preserved for future generations while utilizing the benefits of digital tools and methodologies; it adds a different perspective to the restoration work. However, various issues may arise as a result of inadequate 3D representations. Despite these obstacles, HBIM provides substantial preservation, documentation, and research benefits. Overcoming the challenges of getting 3D models for restoration and documentation needs careful preparation, teamwork, and a thorough understanding of both the technology and the protected cultural asset. Finally, the use of automation and artificial intelligence in data processing and modeling is an area that could benefit from further research. Developing AI tools that can assist in identifying and modeling historical elements and automating certain tasks in HBIM can be valuable.

AUTHOR CONTRIBUTIONS

All the author’s contributions are equally in the manuscript.

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