HBIM for Cultural Heritage: The Case Study of Panayia Karmiotissa Church

Kyriacos Themistocleous[*a,b], Marinos Ioannides[b,c], George Tryfonos[c], Douglas Pritchard[c], Harriet Cliffen[c], Maria Katiri[c], Nenad Jončić[c], Giulia Osti[c], Thomas Rigauts[c], Francesco Ripanti[c], Andreas Anayiotos[a,b]

[a]ERATOSTHENES Centre of Excellence, 2-8 Saripolou, 3036 Limassol, Cyprus; [b]School of Engineering, Cyprus University of Technology, Arch. Kyprianou 30, 3036 Limassol, Cyprus
[c]UNESCO Chair on Digital Cultural Heritage Cyprus University of Technology, Arch. Kyprianou 30, 3036 Limassol, Cyprus

ABSTRACT

HBIM (Heritage Building Information Modelling) is used for the documentation of the Church of Panayia Karmiotissa, near Limassol, Cyprus. The HBIM model is based on the geometric information obtained by digital documentation of the monument. Using laser scanning and Structure for Motion photogrammetric techniques, exterior images were collected using a drone with a 20MP camera and the interior images were taken using an SLR 20 MP camera. Ground control points were used both externally and internally to geo-reference the images using SfM photogrammetry. A Z+F latest technology 3D laser scanner was utilized to scan both the exterior and interior of the church. The images were used in order to create a 3D reconstruction of the Church and used photogrammetry to generate a point cloud of the church and a 3D surface texture model with ortho-images. Following, the data generated by the laser scanner and photogrammetry was processed to create a 3D model to document the church using Heritage Building Information Modeling (HBIM). The main objective of this case study was to create an HBIM model of the Church of Panayia Karmiotissa to digitally register and holistically to document the monument. HBIM is an important tool for the multidisciplinary area of conservators, architects and in general engineer activities, as it provides virtual details that are useful for monitoring, preservation and restoration.

Keywords: Cultural Heritage, Digital Heritage, Holistic Documentation, Heritage BIM, BIM, Photogrammetry, SfM.

*k.themistocleous@cut.ac.cy; k.themistocleous@eratosthenes.org.cy

1. INTRODUCTION

Innovative digital applications provide researchers with powerful tools for the digital acquisition, storage, conservation, recreation, reconstruction, and representation of cultural heritage sites, monuments and objects [1]. Recent developments in photogrammetry technology provide a simple and cost-effective method of generating relatively accurate 3D models from 2D images [2-4]. The process of documenting, creating and implementing the methodology of BIM (Building Information Modeling) for cultural heritage sites provides the opportunity of capturing the cultural heritage information through the use of HBIM (Heritage Building Information Modelling) [5]. This case study examines how BIM can be used for documentation, data collection, information analysis and data extraction to generate detailed architecture drawings and an HBIM model. The geometrical information together with the detailed para- and metadata, extracted from HBIM can be very useful to identify important architectural, material and historical information. Although BIM is a well-known methodology used in the construction industry, HBIM opens a new horizon in the documentation of the past and provides a multi-dimensional approach to cultural heritage.

1.1 BIM and HBIM

Building Information Modelling (BIM) provides a multi-layered, multi-dimensional, multi-disciplinary and parametric digital model of a building that includes building information, including material characteristics of architecture elements and systems through a multi-disciplinary database of information, including architectural, structural, mechanical, electrical and plumbing analyses through the building design process [6– 8]. For cultural heritage, BIM workflows provide the capability to document cultural heritage monuments and collect existing information, thereby enabling better decision-making about preventive maintenance, heritage management, and interpretation. BIM provides documentation for cultural heritage experts to better understand the geometry and the construction methods used for the building in order to understand the cultural heritage site as accurately as possible [9]. The characteristic features of BIM modelling assist cultural heritage experts to manage heritage building information through modelling as an alternative methodology for the documentation of historic places [10].

Heritage building information modeling (HBIM) has provided a useful solution for the interpretation of cultural heritage buildings, archaeological sites, ancient infrastructures, and monuments. This methodology can increase the efficiency of maintenance, preservation restoration and conservation of cultural heritage buildings [11-14]. HBIM requires a digital representation of the site's current condition based on a complete and accurate survey, historical research and on-site observations [16]. It provides a 3D model that describes the geometry of a cultural heritage building into different elements and levels of information, such as materials, construction techniques, physical properties, historical data, documentation, etc., thereby linking them to any related data and assigning them properties & attributes [14,16]. The model created through HBIM also contains the typological relationships of the materials, as well as the sequence that is generated, thereby providing the necessary information to understand the construction of the building over time [17]. Through HBIM, the existing cultural heritage monument can be modeled in a manner that simulates its construction, thereby providing the means to analyse the construction of the building [24] and understand the architectural design, the construction methods, the modifications through time, thereby understanding the history of the cultural monument.

1.2 Study Area

The Carmelite monastery in the Limassol region at Polemidia was established, according to different sources, anytime between the middle of the 13th century A.D. to the start of the 14th century A.D [1]. The monastery was likely abandoned in 1570, following the Ottoman Invasion. Today, only the church remains, with the name of Panagia Karmiotissa. The church was restored by the Department of Antiquities in 2001 following a fire. To the north area of the church there is a cave, where legend states that a holy shrine of the Virgin Mary springs miraculously. On the north side of the church lie the ruins of the monastery complex that are reduced to heaps of stones. The Church of Panagia Karmiotissa is the only preserved Gothic church in the Limassol area during the time of the Frankish House of Lusignan in Cyprus. The Ruined Carmelite Church and Monastery have been declared an ancient monument by the Antiquities Department.

The Carmelite monastery church was erected in strict Gothic form without any structural adornment with a rectangular single nave with a straight choir closure and illuminated by a few lancet windows (Figure 1). Detailed descriptions of the church come from the art historians Enlart [18] and Jeffery [19], who were able to examine the remains of a narthex on the west side of the monastery church around the end of the 1800s and provided a detailed description of the church. The church consists of a simple rectangular envelope built in irregular courses of roughly shaped stones with rubble injected in the joints. The church is built in the single-aisle basilica style, with a pointed, arched roof reinforced in the middle with a pointed bow and Gothic architecture elements. The dimensions of the church are 16.20 meters long and 5.50 wide [18]. The monastery church was erected in Gothic form with a rectangular single nave with a straight choir closure and a few lancet windows. It can only be identified as a Greek Orthodox Church as a result of the addition of the Greek Orthodox iconostasis. Due to its historical importance the monument is included as a special case study in the EU ERA Chair Mnemosyne project.

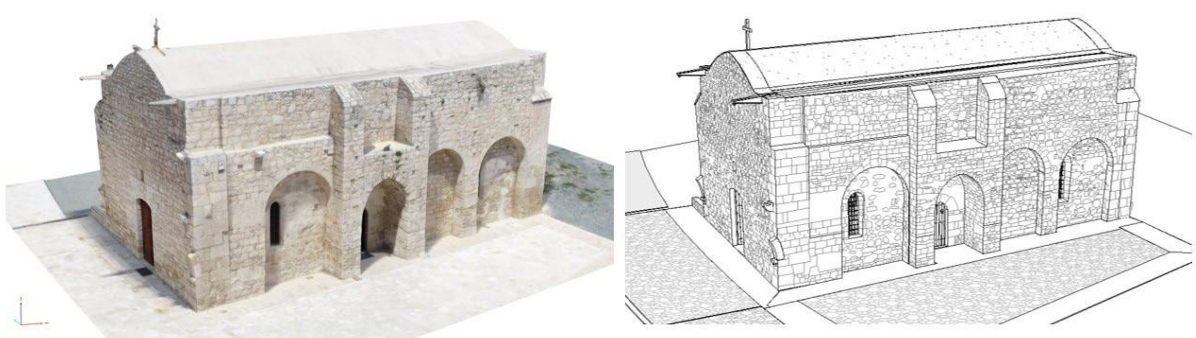

Figure 1: Photogrammetry and BIM representation of the Panagia Karmiotissa Church

2. METHODOLOGY

BIM relies on information modeling database to generate and manage geometric 3D digital models, materials and functional parameters and characteristics of a building. Once the 3D model is created, it is possible to update, extract drawings, floor plans, elevations and sections [24]. The advantage of BIM in comparison with 3D modeling is the ability to update any parameter and information instantly to all related information and drawings, dimensions, and relate that information to different dimensions (4D-Time, 5D-Cost, 6D-Sustainability and 7D-Management and Maintenance) into the building model. BIM also provides the capability to communicate through different software for various disciplines and provide historical information. The BIM advantage to include different level of graphic detail, level of accuracy and Level of Development (LOD) in 3D modeling makes BIM an ideal methodology for Cultural heritage documentation.

The digital documentation of the church included laser scanning, in combination with the images acquired through UAV and SLR cameras that were processed through photogrammetry that created a digital BIM model of the church. The methodology used to document the church included a photogrammetric survey [1, 9] using different methods of acquiring images of the exterior and interior of the church. Ground control points (GCPs) were first placed inside and outside of the church in order to acquire topographic coordinates and reference the geometry of the building. The inside of the church was photographed using a hand-held camera, while the outside of the church was photographed using a camera mounted on a UAV. The high-resolution aerial imagery obtained from the UAVs and the RGB cameras were imported into Structure from Motion (SfM) photogrammetry to create rapid and automated generation of a point cloud model and 3D mesh model.

Using the BIM workflows, the BIM 3D model was developed by using the survey data [4, 20], the laser scanner point clouds and the dense point cloud of the church generated from photogrammetry [5, 21] (Figure 2). After the BIM model was constructed, drawings of the floor plan, elevations, and sections of the church were generated directly from the BIM model, including information such as material, color, height, thickness, etc., which was added to each component in the BIM database [5, 9].

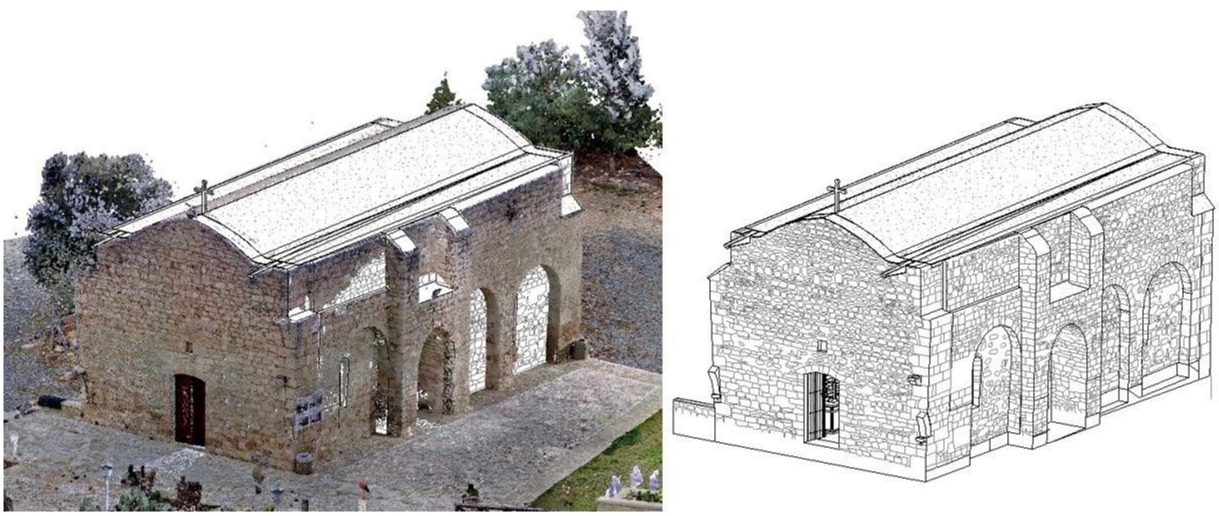

Figure 2: Left: laser scanner and photogrammetry point clouds; Right: BIM model

The point cloud obtained by the photogrammetric process, together with the collected historical information, served as the basis to generate a HBIM, which contained all the building components, structural elements, materials and semantic information [5, 17]. The church was digitally reconstructed in a 3D BIM model, where it was then processed to produce an HBIM in order to create a prototype for a holistic documentation and further study [5] (Figure 3).

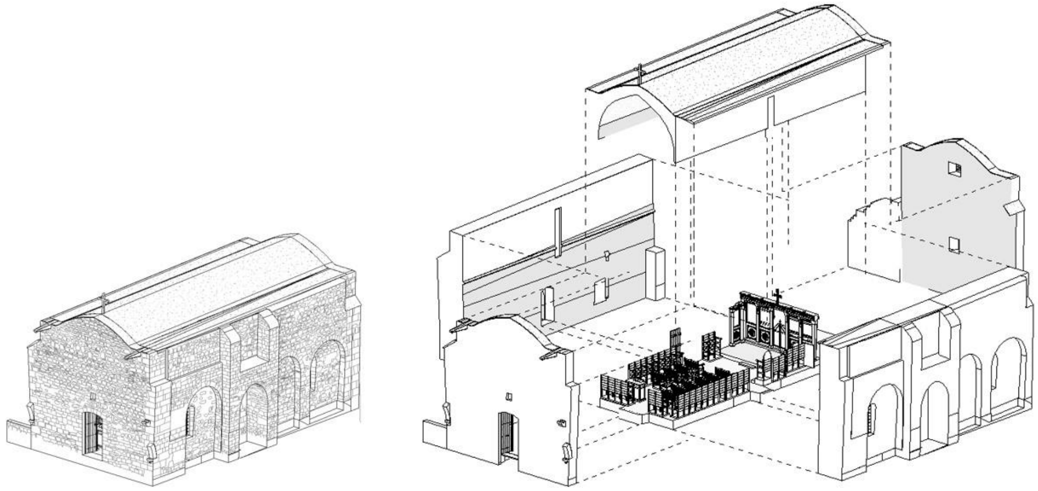

Figure 3: HBIM model building components of the Panagia Karmiotissa Church

The dense point cloud generated from photogrammetry is the necessary information required in order to use it as a basis for developing a BIM model. The HBIM model designed from the point cloud obtained by UAV photogrammetry and laser scanning provided the accuracy needed not only revealed the geometry of the structure but also provides information for the design and construction processes the building was constructed. This process helps the architects and researchers understand the construction methods and the architectural elements. Furthermore, photogrammetry in combination with BIM provide the necessary basis for digital twin models for the structural survey and monitoring [4]. BIM also provides information about the geometrical and mechanical properties of the Heritage structure and performed structural analysis of the structure using finite element model [22, 23]. Autodesk Revit BIM software used for this study provided the capability to link the point cloud model created from the photogrammetry in order to create the 3D BIM modelling and a library of parametric elements needed for the HBIM model. HBIM also provides the graphical output needed to understand the cultural heritage monument and the information needed for research, preservation, materials, conservation and documentation.

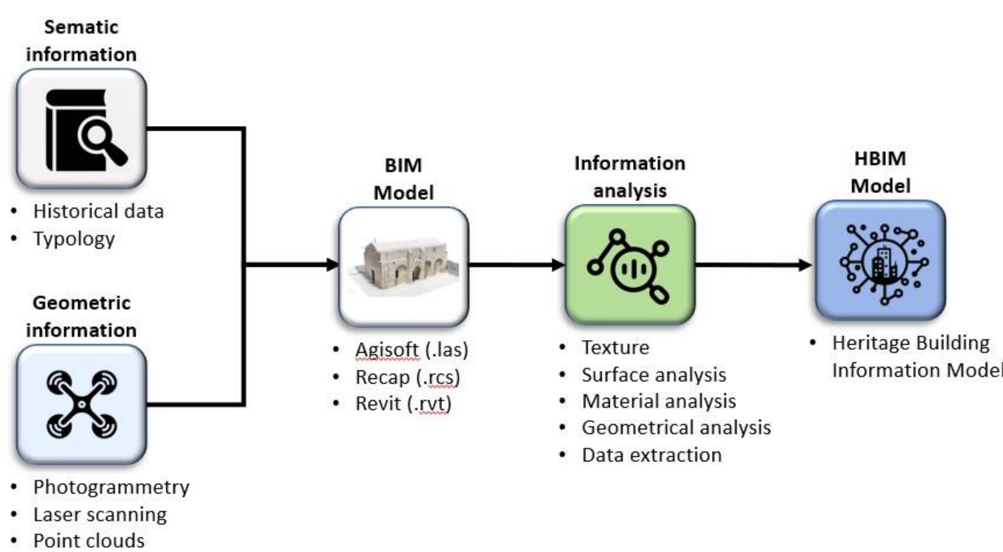

Figure 4: HBIM methodology used in this study

Figure 4 describes the methodology used in this study. In order to generate a historic BIM model, it was necessary to include semantic and geometric information. Semantic information included historical data and building typology, whereas geometric information included photogrammetry, laser scanning and point cloud generation. The resulting data were imported to a BIM environment where a BIM model was generated through a series of workflows. Semantic information, as well as typological information, were imported to the BIM model in order to generate an HBIM database. In creating a BIM model for the Church of Panayia Karmiotissa, it was necessary to manually create a library containing all the necessary parametric elements (doors, windows, etc) as well as typological relationships of the materials. These parameters and relationships, provide the necessary information to understand the structural constructive evolution of the building and its spatial, temporal and social context.

3. RESULTS

The history of the Church of Panayia Karmiotissa originated when Carmelite friars settled in Cyprus during the 3rd Crusade [1]. However, it is unknown exactly when the monastery was established and when the church was built [26].
According to Enlart, the church is consistent with the architecture of churches built in the 13th Century [18]. As most of the history of the church is unknown, one of the objectives of this study is to create a HBIM in order to document the church and investigate the hidden history. One of the first outcomes of the documentation through HBIM is to establish the relationships of the building through architecture documentation as shown in the floorplan below (Figure 5). In 2001, a wooden iconostasis was added in front of the altar by the Department of Antiquities and the Bishopric of Limassol to create a functioning Greek Orthodox church. The iconostasis was placed in a respectful manner without damaging or intervening with the building, thereby protecting the history of the building, as shown in Figure 5.

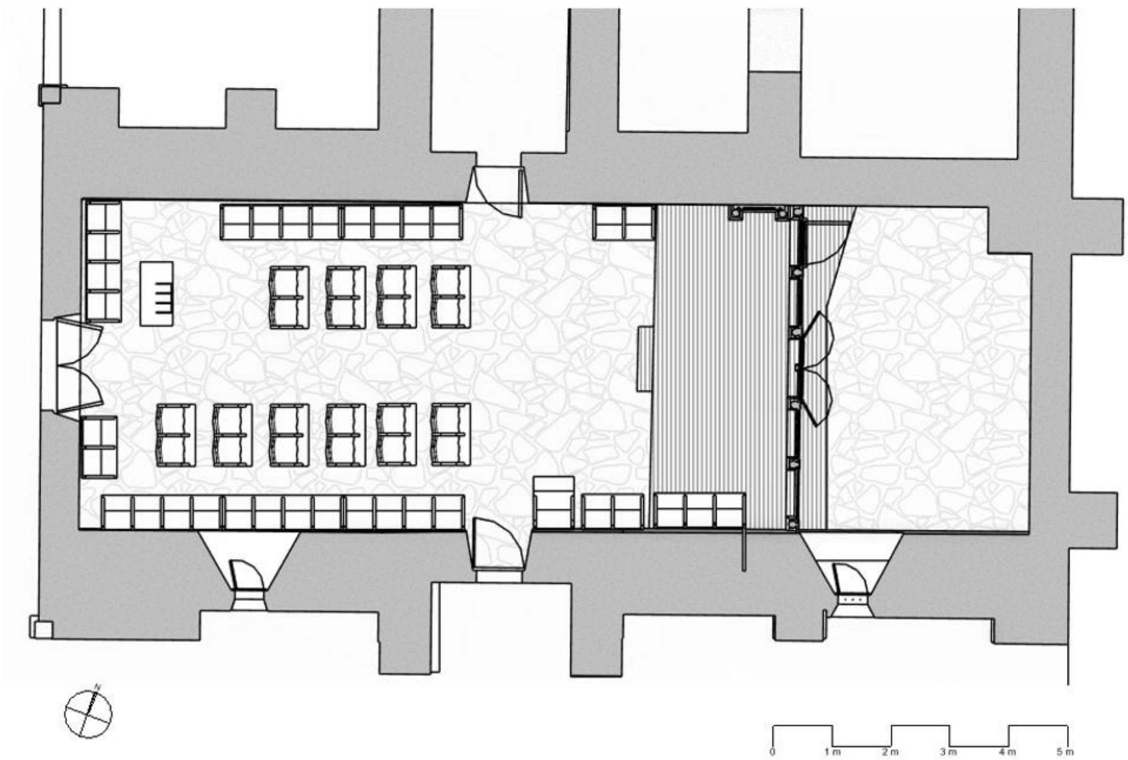

Figure 5: Floorplan of the Church of Panayia Karmiotissa

Using the methodology described above, the most important information needed in the HBIM methodology is the collection of semantic, geometric and historical information. The geometric information needed to generate the HBIM modeling is the generation of accurate point clouds that will be used in order to generate the 3D model. Laser scanning and Photogrammetry are established as the most reliable methods of generating accurate point clouds that can be used as a basis for the BIM model. The BIM model created in this study used a special library of parametric BIM objects that have been designed as multi-disciplinary components that are custom-made for the Church of Panayia Karmiotissa (Figure 6).

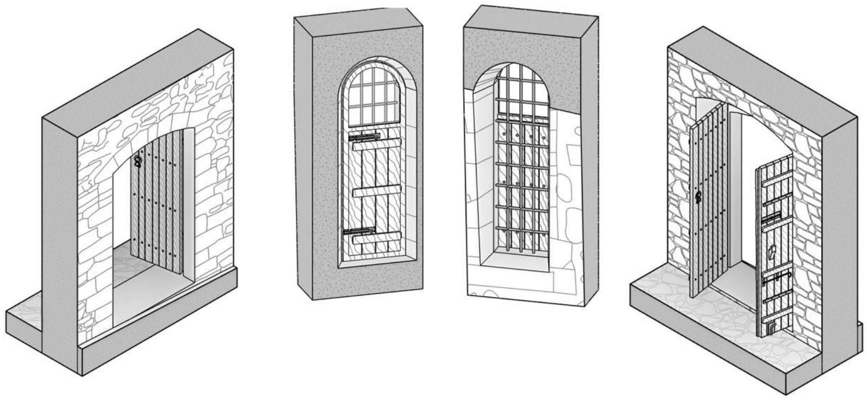

Figure 6: Library of parametric BIM objects (Doors and Windows)

The HBIM model created is a detailed model provides material textures and colors and generates technical documentation (floor plans, sections, details, projections, etc.) and quantitative and qualitative information. The model created through HBIM also contains semantic and typological relationships. These relationships provide the necessary information to understand the structure of the building as well as its spatial, temporal and social contextualization. The use of photogrammetric results such as dense point clouds, orthophotos, materials, textures and geometry become basic requirements of graphic documentation.

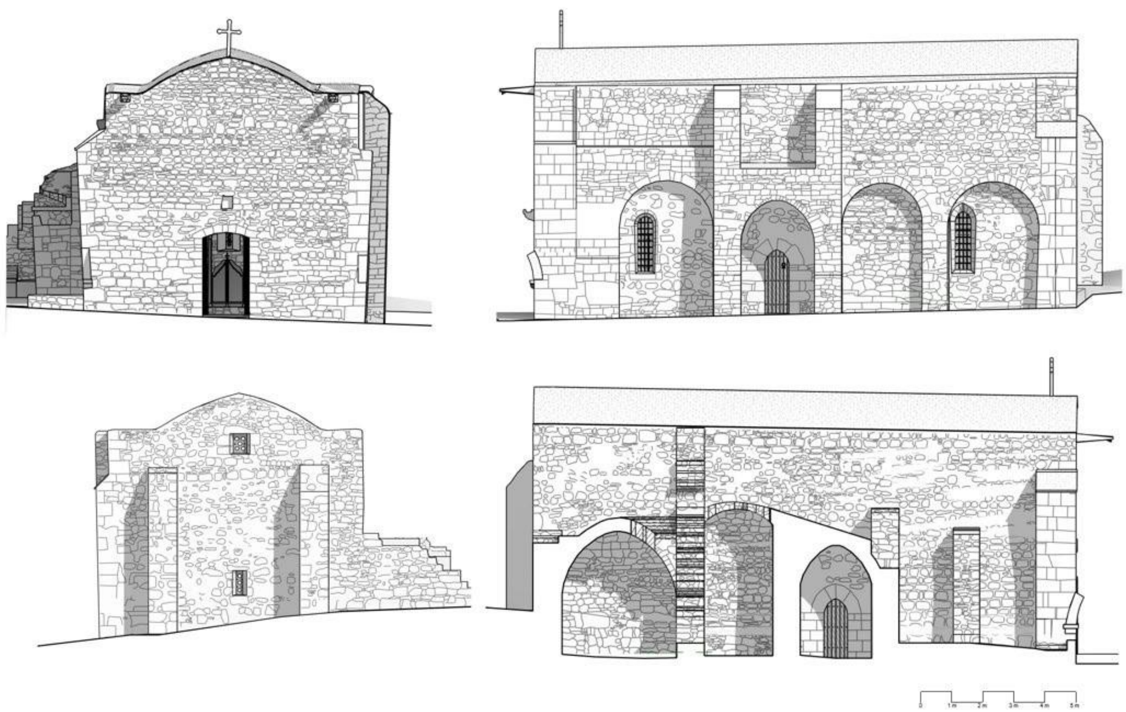

Figure 7: Elevations drawings of the Church generated from the BIM model

The BIM model generated from the dense cloud geometric information ought to reflect the real structural geometry and have the accuracy and integrity of the 3D photogrammetric and Laser scanner survey. This is important as the accurate documentation of the geometric information is one of the important parameters of the HBIM model. In this study, the comparison of the elevations of the photogrammetric survey shows an accurate geometric correlation with the drawing elevations generated from the HBIM model of the Church in Figure 7.

The geometry of the BIM model shows that the church was erected in strict Gothic forms without any structural adornment with a rectangular single nave with a pointed barrel vault roof and illuminated by a few lancet windows. The arched roof and single nave are evident in the sections in Figure 8, both in the photogrammetric and HBIM model.

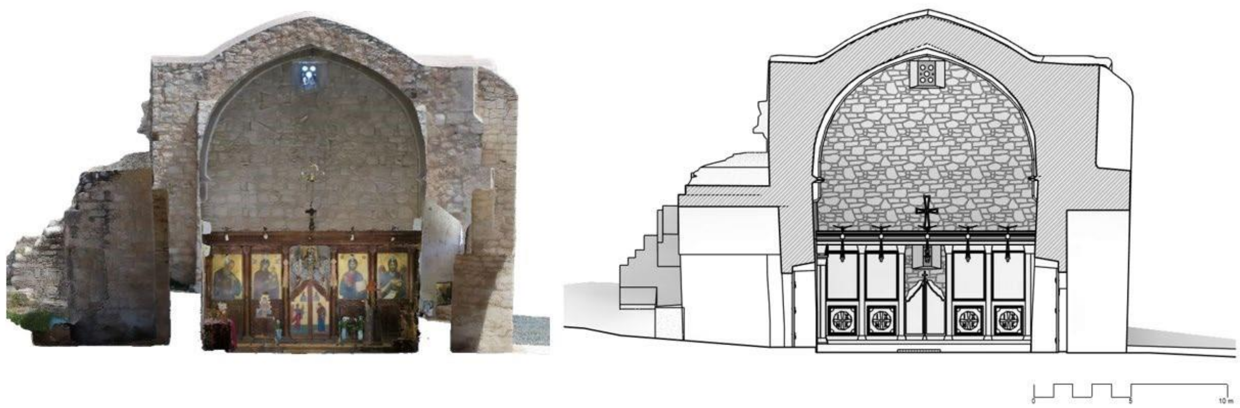

Figure 8: Sections of the Church generated from Photogrammetry (left) and HBIM (right) model showing the exterior and interior geometry

During the HBIM model generation, the structural elements of the church provided information about the historical elements of the building. The most important feature of the church is the transverse arch that is evident in the middle of the vaulted ceiling. As shown in Figure 6 and 7, there are buttresses on the side walls that support the weight of the vaulted ceiling, which shows the Gothic influence of the church. There are two small rectangular windows on the wall of the nave and two long lancet windows on each side of the choir, which illuminates the church during the day. The exterior and interior of the church are made from roughly cut stone that creates a rough texture that reflects the age of the church.

4. CONCLUSIONS

HBIM was used as a tool for monitoring, conservation, preservation and restoration of the Church of Panayia Karmiotissa and its cultural heritage. The analysis provided a valuable resource of information to researchers, architects and archaeologists for documenting, analysing and contextualizing the history of the cultural heritage of the site and provided the capability to understand its geometry and structure. This is the first time the Church of Panayia Karmiotissa has been documented in such detail as a record for future generations. Cultural heritage buildings provide a tangible connection to the past. As a result, documentation of cultural heritage monuments is necessary to preserve understanding of history for future generations. The importance of HBIM and the information collected to generate an accurate representation of cultural heritage monuments is essential for the study of any cultural heritage site.
The Cyprus University of Technology team managed to prepare the detailed documentation of the monument and handed over the data to the Committee of the Church and to the engineers of the Cyprus Department of Antiquities during a special ceremony.

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