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GEOMATIC DATA FOR HISTORIC BUILDINGS. THE CASE STUDY OF THE CATHOLIC CHURCH OF ST. LUKE IN ATHENS, GREECE

Abstract

The application of contemporary methods, tools and the equipment to produce technical documentation for heritage buildings is a cuttingedge topic that brings together engineers from various fields of technical sciences. Focusing on one specific heritage example, that is the church of St. Luke in Athens, this paper explains entire methodological process of generating the data on physical characteristics of architectural objects by combining several geo-spatial methods and techniques. The final product is the spatial model of church building, formed from generated point cloud. The model represents a basis from which different forms of technical documentation can be produced, from layouts and elevations, to sections, to details, to 3D representations.

Keywords: heritage buildings, geo-spatial methods, BIM, technical documentation.

ГЕОМАТСКИ ПОДАЦИ ЗА ОБЈЕКТЕ ОД ИСТОРИЈСКОГ ЗНАЧАЈА. СТУДИЈА СЛУЧАЈА КАТОЛИЧКЕ ЦРКВЕ СВ. ЛУКЕ У АТИНИ, ГРЧКА

Сажетак

Примена савремених метода, алата и опреме у сврху израде техничке документације за објекте који припадају градитељском наслеђу је актуелна тема која окупља инжењере из различитих области техничких наука. У овом раду је на примеру цркве Св. Луке у Атини објашњен целокупан процес генерисања података о физичким карактеристикама архитектонских објеката, комбиновањем више гео-просторних метода и техника. Затим је из генерисаног облака тачака формиран просторни модел објекта цркве. Тиме је успостављена основа са које се даље могу генерисати различите форме техничке документације, од основа, пресека, изгледа, детаља, до 3Д приказа.

Кључне ријечи: градитељско наслеђе, гео-просторне методе, БИМ, техничка документација.

1. INTRODUCTION

In contemporary concepts such as smart or the virtual city, the three-dimensional (3D) models of built structures play an important role. Geomatics techniques come to the fore in creating such models. The three-dimensional mapping techniques like photogrammetry, terrestrial and Unmanned Aerial Vehicle (UAV) / drone photogrammetry, or the terrestrial and aerial laser scanning, all enable efficient data acquisition. The application of mentioned techniques leads to the generation of point clouds, i.e., the 3D documentation of processed physical structures.

One common approach to generate 3D building models is to combine footprint data with the data collected by airborne laser scanning (ALS) for roof structures as well as the terrestrial laser scanning (TLS) for façades [1-3]. However, the ALS does not have the accuracy of TLS technology that remains the main data source for an exact 3D building model, e.g., [4-6]. In addition, the drone photogrammetry has gained much popularity due to the ease of use and the cost effectiveness in mapping sites and structures, all of which can successfully be achieved with a low-altitude image-based survey, e.g., [7-9]. In any case, the mapping of areas and the buildings requires a lot of human resources and a large amount of time. A community-based mapping or a participatory mapping method may be options to facilitate a 3D digitization process and support smart cities, especially when it comes to the built heritage assets, e.g., [10].

Heritage is almost always related to the concept of a territory, as both a geographical and a cultural entity. Heritage is also related to the social and community organizations that nowadays are often formalized as territorial administrative units. Being a collective property, heritage tells the history – of people or a territory – that is passed on from one generation to the next. Through the heritage, the features of communities and the territories gain timelessness and the distinctive character, thus representing the base of construction of a common cultural identity. One continuous task, therefore, is to keep recognizing those material and immaterial elements that are attached to a certain territory and its social environment as key components of cultural identification.

One such identified example is the Catholic church of St. Luke built in the middle of the 19th century in a newly formed settlement Heraklion in Athens. Spatial and socio-cultural development of Heraklion (Figure 1) over time was steady. Nowadays, this neighborhood represents a thriving suburb of Athens located about 7 km from the city center. In parallel, the church of St. Luke underwent a number of changes throughout its history, but to this day it remains a valuable example of sacral architecture that as such will be studied in this paper.

Figure 1. *Life in Heraklion over the course of the 20th century. Left: Year 1900. Middle: 1923 – The feast of Saint Luke (with photographed car of Otto Fix). Right: Heraklion in 1957. [11]*

The work carried out represents one part of a greater plan to establish the key aspects of local cultural identity of Heraklion. The study focuses on production of digital documentation record of the church of St. Luke, using a variety of geospatial techniques. Digital management of heritage buildings can be successfully achieved through the BIM (Building Information Modelling / Management) models. For historical buildings, BIM can be referred to as HBOM (Historical Building Object Modelling) [12], or hBIM (historical or heritage BIM). In geodetic and architectural surveying, BIM model is commonly displayed in a flexible form that allows to introduce physical changes in time, and to add different physical details. Such a model is proven to be very useful for heritage buildings, too, as it allows accumulating different types of data in one single database. Whilst the work regarding hBIM methodology has already been published, there still is a need to carry out researches that will provide an understanding of the potential of BIM for heritage buildings.

Relevant literature on hBIM is addressing several issues such as input data quality and the quantity, e.g., [13, 14]. Besides the geometrical content, the type of data texture is also important. Texture can present the information concerning age, material type, etc., but does not necessarily need to be realistic, because it can be created from other data sources like infrared images, e.g., [15]. The texture can be provided by BIM software, or created in a customized way based on the images of a subject structure.

The paper is structured in four sections. Section 2 describes history and the architecture of selected case study that is the St. Luke church, and explains used geomatics methods and techniques, and the data field operations. Section 3 describes data processing of point clouds, and the development of 3D model to be imported to the BIM. Finally, Section 4 discusses practical application of produced results, and provides the concluding remarks.

2. MATERIAL AND METHODS

2.1. ST. LUKE CHURCH IN ATHENS

Dozens of Bavarians came to Athens with King Otto in 1832 and subsequently founded Heraklion (Arakli) settlement. The center of the settlement was so-called Old Heraklion, better known among locals as Germanochori (Eng. German village). The legend says that Otto looked for an area for his country house and the settlement for families of his entourages. To select an optimal location, Otto ordered his courtiers to slaughter lambs and hang them on trees in various parts of Attica. He would choose the place where the lambs would rot later, since there would be less humidity and generally a better climate. Eventually, the lambs rotted with a longest delay in today's Othonos Square in Old Heraklion. Thus, in 1837, Otto founded – with his first commander Christopher Nezer – the Bavarian Military Colony of Heraklion. About 33 persons, courtiers and mercenaries, so settled at the place that represents the yeast of today's Heraklion community. According to the 1838 census, Heraklion had 42 inhabitants, majority of which were the Catholics [18]. For spiritual needs of inhabitants, the priest of the Palace, Fr. Arneth, ascended to Arakli at that time, suggesting construction of a holy temple with the Evangelist Luke as patron.

The history of St. Luke church in Heraklion (Figure 2) can be observed through three phases of spatial expansion of the temple building (Figure 3), as well as through the critical damages, i.e., the extensive renewal works.

Figure 2. *Location of the church of St. Luke. Left: Position in the City of Athens. Right: 3D presentation of Heraklion with the St. Luke church in the center. [16, 17]*

The initial church project was developed in 1840, and the construction marked by ceremonial blessing of foundations began in 1842. The design features several architectural elements typical of the work of Danish designer Hans Christian Hansen who at that time was the most prominent architect and planner in Athens. Hansen's idea was to build a small temple with rectangular plan and the basic Gothic-style elements. The roof of the church is saddle-like. The base was 17,45 meters long.

Light-colored wooden ceiling that covers the nave is divided into aisles by septa, whose coffers – 105 in number – are ornamented with yellow patterns. Thirty sigmoid wooden jewels adorn the side walls. The roof, as well as all interior and exterior decoration of the church, was constructed by Joseph Martinellis. The entrance was crowned by lobed glass. Narrow and high window openings finish with a zigzagged line at the top. Two middle windows were added later. The triumphal arch is also zigzagged. Above the main steps is the icon of the Evangelist Luke. On each side of the apse are two altars, to the right of the Virgin Mary and to the left of the Sacred Heart of Jesus. The construction was completed in 1845, and the inauguration took place on the 18th of October the same year [19].

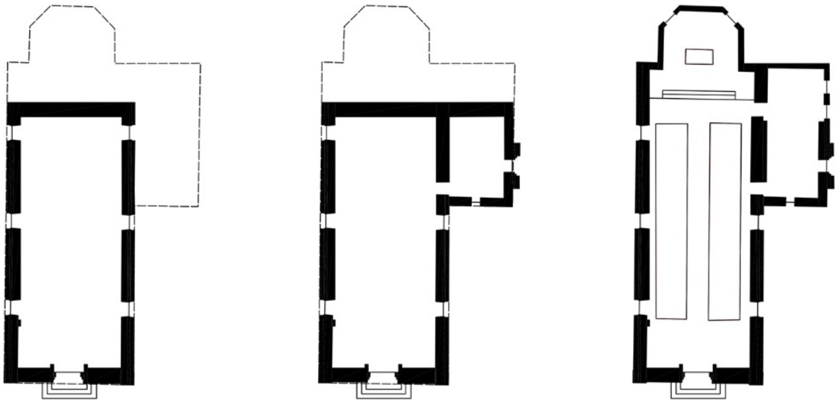

Figure 3. *Three phases of spatial expansion of St. Luke church building. Left: Period 1845-1900. Middle: 1900-1972. Right: 1972-today. [Authors]*

On May the 8th, 1847, lighting hit the St. Luke temple and destroyed one part of its spire, up to the roof, consequently breaking panes and the sanctuary. After more than half of century, at the beginning of 1900, architect Max Schultze initiated the renovation of damaged church. Present vestry and the spire originate from this period. Although the church was in bad conditions for a long period of time, its significance was not lost. This can be witnessed by the Kaupert's map from 1878 where the St. Luke church was shown probably for the first time. Namely, German topographer Johann August Kaupert, famous for land-surveying in Athens and the work "Atlas of Athens", represented the whole Attica in 1:25000 scale maps. In the specific map (Figure 4), one can see the St. Luke church (Kirche is the German word for church) with a few nearby houses. The village Heraklion continued to grow and subsequently became incorporated into urban area of Athens. Urban map from 1936 (Figure 5) shows the church and the adjacent buildings.

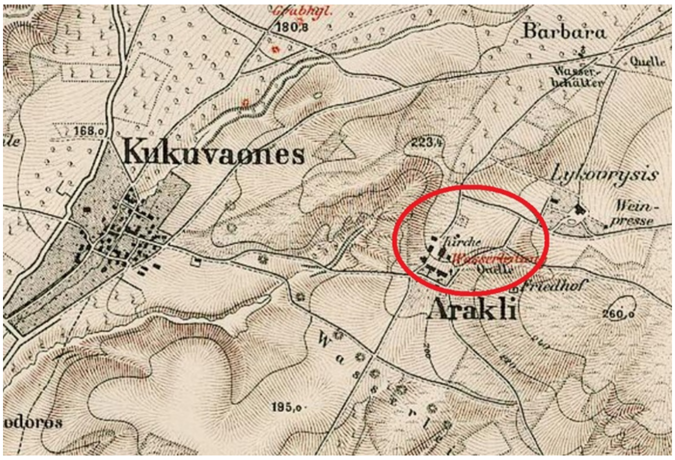

Figure 4. *Kaupert's map with marked church of St. Luke, 1878 [20]*

Figure 5. *Urban plan of Heraklion, 1936 [21]*

During extensive church repair in 1931, two marble inscriptions were built inside, from both sides of the entrance [22]. In 1950, the entrance door of the church was renewed, the new, larger bell named Hope mounted (Figure 6), and the facades were painted.

Figure 6. *The bell Hope installed at the St. Luke church in 1950 [23]*

The last sizable reconstruction of the St. Luke church building was initiated in 1965 and completed in 1972, under supervision of the Reverend Nicholas Vidalis. Introduced changes correspond to the spatial expansion of the temple (Figures 3, 7, 8). Namely, church building was extended in length to the side of the sanctuary. Next to that, several existing temple elements, such as the catechism room, priest's room, and the meeting room, were demolished and again rebuilt to improve overall structural and the aesthetic quality [22].

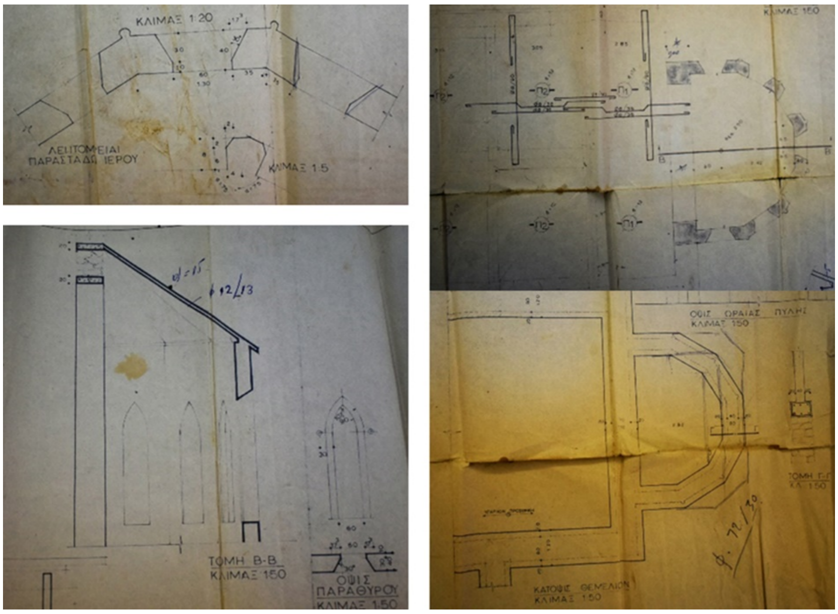

Figure 7. *Drawings for spatial extension of the St. Luke church, 1970 [23]*

Figure 8. *Construction works at the St. Luke church in 1972 [23]*

On the two columns at the church front, from both sides of the spire, two statuettes were placed, one of the Apostle Peter and another of the Apostle Paul, just as the architect Theophilus Hansen originally planned (Figure 9). Next to the works on the church building, the new presbytery was constructed, based on the project of Dimitris Sarros (Figure 10). Furthermore, Reverend don Vidalis enriched the interior of temple with five large and three small reliquaries with bones of Christian “protomartyrs” originating from the Holy Church of St. Mark in Zakynthos, earlier destroyed in earthquake. The reliquaries bore old lead seals and illegible Latin inscriptions. For these sacred relics, wooden carved display cases of 1.85 m width and 2.15 m height were ordered. The showcases of Gothic style were crafted by woodcarver Efstathios Gaitanopoulos.

Figure 9. *Statuettes of the Apostles Peter and Paul at the church front [Photos by authors]*

Figure 10. *Old and new presbytery next to the St. Luke church [23]*

Parallel to the works on the church building, its immediate surrounding was changed as well. In 1968, the copper bust of King Otto was erected in church garden. The unveiling took place on the 16th of June, at the occasion of the 100th anniversary of his death. The bust was created by Georgios Maltezos, the well-known writer of the “Heraklion Chronicle”. Reimbursement of costs for melting the copper was offered by Paola Huber from Ellwangeu/Jagst, Germany, in memory of her father Maximilian who grew up in Heraklion. Other expenses were handled by the Church. This way, the descendants of Bavarians in the old military colony wanted to honor the founder of their settlement after 130 years.

The church of St. Luke is surrounded by the old Pine Park. In one of its corners, there is the Gothic-style column designed by sculptor Nick Georgantis. The column is fully aesthetically harmonized with the St. Luke church and the whole environment. To the right of the entrance to the park, there is a pilgrimage hall with an inscription. An inscription is also built into the left wall of the park, which belongs to the municipality of Heraklion. East of the church of St. Luke, and at a distance of about three hundred yards, the Cemetery of the Catholics of Old Heraklion extends on a hill. This cemetery is one of the most well-preserved monuments. The cemetery of the Orthodox inhabitants of Old Heraklion is located right next to that of Catholics since 1936. Among the many sepulchers, the Fix family tomb in the middle of the Orthodox cemetery is distinguishing.

2.2. METHODOLOGY

Geometric documentation of structures like churches presents certain difficulties due to large height differences, abundant surface details, or the existence of hidden surfaces. Therefore, the synergy of data is essential to significantly increase the amount of geospatial information and to obtain more accurate results from the documentation process. To date, 3-dimensional (3D) high detailed visualization products are easily available, which convey the accuracy of original data. In this work, the combination of laser scanner data with geodetic reference provided by GPS measurements (38° 03'34.94421"N 23° 46'21.49187"E 220.825) was implemented.

For complete church recording, the capture of twenty-seven scans was performed around the perimeter of the building (Figure 11), and inside (Figure 12). Leica Geosystems Blk360 laser scanner was used for scanning. The distances between the scanner and the object were less than 20 m. Scan overlap during data capture was between 40-60%.

Figure 11. *Point cloud externally capturing the church building [Authors]*

Figure 12. *Laser scanning process for capturing the church structure from inside [Authors]*

A custom-made mount was used during the capture of twenty scans so that the scanner could be mounted on a tripod and leveled. The acquired scans were directly referenced in the state reference system (namely EGSA87) using GNSS surveying. To calculate external accuracy of merged point cloud, the special targets (Figure 13) measured by using Leica Geosystems TCR1202 + total station (quoted precision of 2 " and 1mm + -2ppm) were used.

Due to occlusion during the scanning survey, and the difficulty to find suitable locations and set-up the scanner to have direct visibility of the roof, it was decided to use digital imagery taken from the drone and achieve the full building coverage that way. The model DJI Mavic Mini was used in that purpose. It is a light, compact and easy-to-use drone with a 12MP camera, suitable for close-range flights and applications. In total, 41 shot were made, from them 15 being vertical just above the church, and the rest were side shots with the angles from 30o-60o (Figure 14). The vertical shots were made from a height of 40 m above the ground. All of the images have an overlap of at least

40%. No flight planning software was used as it was quite easy to calculate the overlaps due to the small size of the church building.

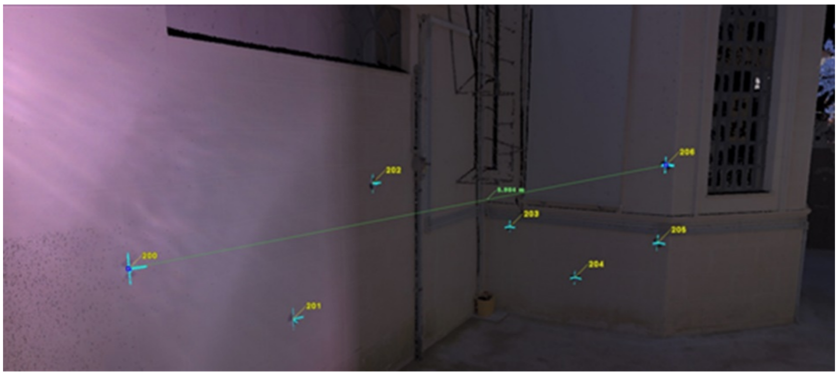

Figure 13. *Tie points as seen in point clouds [Authors]*

Figure 14. *Side and vertical drone capture [Authors]*

The proprietary software Agisoft Photoscan was used to process obtained images. All produced images were added to the model, but finally 35 of them were used. Following the alignment and the optimization of images, the sparse and the dense cloud were produced. Figure 15 depicts one detail of the dense cloud from the roof of the church. The dense cloud has an average density of 27.6 points/cm^2. Moreover, the model was georeferenced by using control points, so that the exported point cloud can be combined with the point cloud that was produced by using laser scanner.

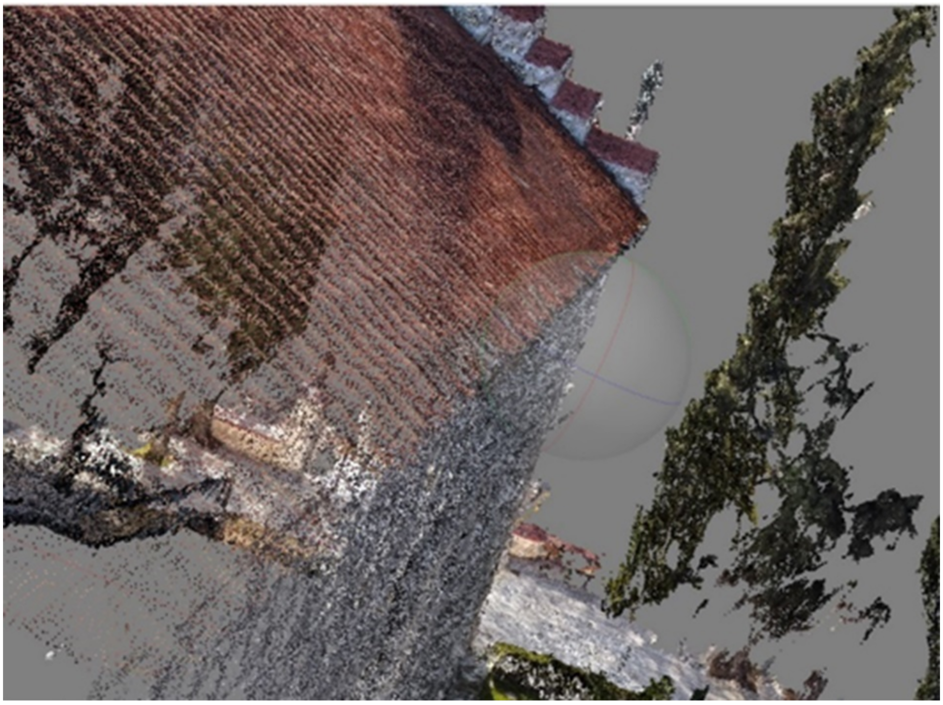

Figure 15. *Dense cloud detail [Authors]*

3. DATA PROCESSING AND RESULTS

Point clouds were processed using the proprietary software platform Leica Geosystems Cyclone. The final registered point cloud had an accuracy of less than 1cm (Figure 16).

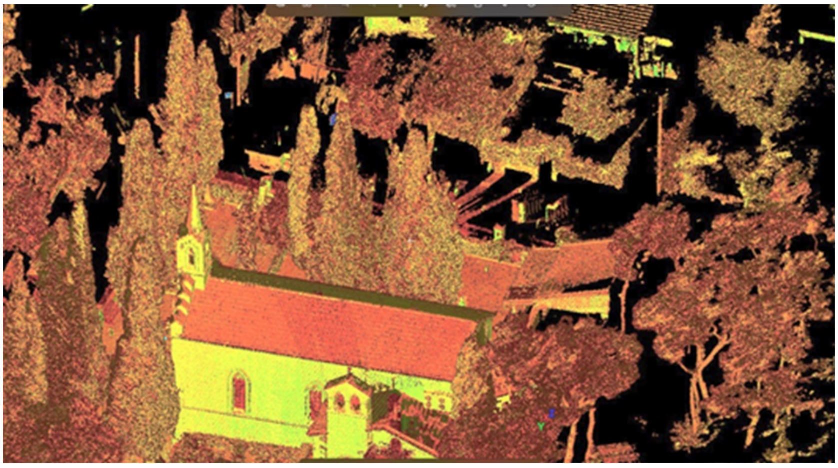

Figure 16. *The view of registered point cloud [Authors]*

The difference between the coordinates derived by total station measurements and the modelled point cloud gave RMS in the order of 1.2 cm.
The main product of combined laser data and imagery data was orthophoto of the church (Figure 17).

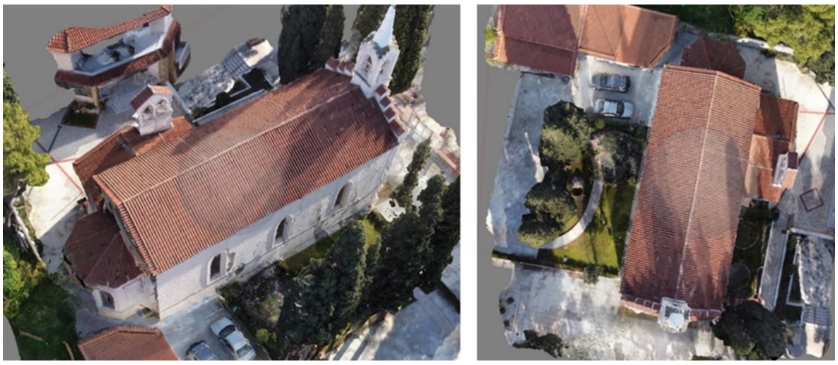

Figure 17. *Left: Textured side view of the model. Right: Orthophoto. [Authors]*

After determining the levels of modelled building and tying the objects to their levels, walls, windows, doors, roof and stairs were modelled with the use of created families (Figure 18).

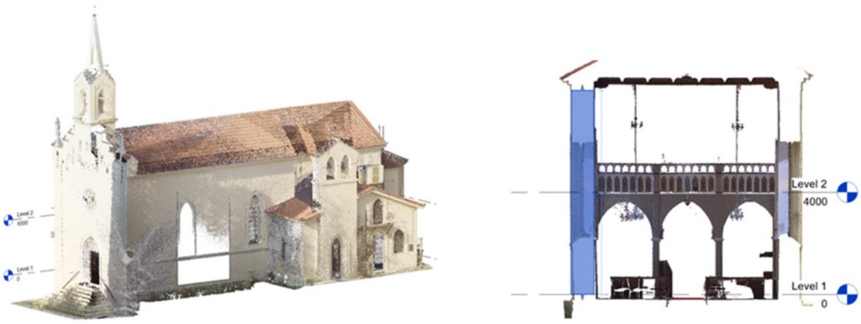

Figure 18. *Left: Reference height set at certain levels. Right: Remodeled BIM model along the point cloud data information. [Authors]*

The BIM church model was created in the last work stage. Generally, BIM offers advantages to architects and engineers as they can automatically extract 2D plans with all georeferenced views.

Moreover, additional views can be automatically extracted at any time and not limited to the predetermined set of 2D drawings.

In this work, the BIM ‑ REVIT (Revit Autodesk) environment was used. Registered 3D point cloud was exported in Recap format and then imported to the BIM for further modelling. Although detailed description of modelling process is not within the context of this article, the indicative results are shown to depict some aspects of the model. Overall, regular surfaces were modelled using the Architecture tool that exists in Revit internal library. The irregular surfaces were modelled externally by creating Component Families. For presented model, the components from standard BIM content libraries were used (e.g., arched features) and others were created when structural components (e.g., the windows) were not readily available.

To model the subject church building, a mixed approach combining simple 3D geometry with a number of repeatable parametric components was applied. During the BIM modelling, a series of compromises between modelling time, file size and model functionality (e.g., using parametric BIM components rather than the imported mesh geometry), versus modelling tolerance (i.e., how close the model is to the point cloud dataset that constitutes the primary survey record) had to be made. Figure 19 presents the final produced 3D model of the St. Luke church.

Once the components are modelled, they could be used to further produce technical documentation such as horizontal plans, elevations, sections, details and perspectives. The advantage of the BIM model over the final point cloud of a structure, amongst others, is that it offers a possibility to extract sections in longitudinal and transversal directions. These sections show structural building composition and the dimensions of various elements and surfaces.

In conclusion, the church of St. Luke in Heraklion, Athens, was fully processed, from geomatics recordings to the BIM modelling, and every architectural component was parameterized.

Figure 19. *BIM model of the St. Luke church building [Authors]*

4. DISCUSSION AND CONCLUSIONS

This work presented one specific possibility to generate and process geomatic data for cultural heritage buildings. To demonstrate applied methods, and to explain the process of obtaining the data, a distinct example was chosen, and that is the Catholic church of St. Luke in the settlement Heraklion in Athens, the capital of Greece. The temple, built under the order of the Greek King Otto, underwent several significant changes over time, yet its symbolic, architectural and functional values are preserved. As such, the church of St. Luke represents a valuable example of historical buildings. The emergence and the changes on temple building over time have not been holistically described in literature so far, and, in that sense, the conducted work provides contribution to existing opus of valuable examples of sacred architecture in Greece and beyond. Next to that, the contribution of this work is reflected in its educational purpose, where growing interest in digital methods for cultural heritage documenting was met by the step-by-step explanation of methodology used to harvest and process relevant data.

Recording of heritage architecture using contemporary methods, tools and equipment, as shown in this paper, shortens the time required to collect input data on physical characteristics, and the reasons for collecting these data in practice are diverse [24]. Where obtained geomatic information about architectural objects represent an input for further digital processing exclusively for the purpose of visual presentation of cultural heritage [25], a variety of visualization software tools are available.

On the other hand, geometric data harvesting can be the first step in the process of developing the projects to assess existing state of building structure, estimate risk of damage and the deterioration, develop maintenance plans, or plan reconstruction of heritage architecture. In these cases, the accuracy of recording, the details, and the possibility to manipulate with produced 3D models, 2D plans and the sections, are crucial. Consequently, the possibility of choosing the software tools comes down to complex building information modeling (BIM) programs, e.g., [26, 27], with multiple integrated functions necessary for the work of professional engineers from different technical branches. In this context, the use of the state-of-the-art digital methods represents an important issue in efforts to preserve tangible heritage assets.

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