3D Modeling of Sidon Sea Castle Utilizing Terrestrial Laser Scanner Combined with Photogrammetry

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DOI: https://doi.org/10.52939/ijg.v20i5.3227

Abstract
The progress in geodetic survey and data collection technology has led to the development of highly precise tools and techniques that can efficiently gather large amounts of spatial data. As a result, there is an increasing demand for these technologies in various fields, such as archaeology and historical documentation, due to their ability to create and monitor accurate 3D models using computer programs. Regarding archaeological sites, it is important to survey, record and document archaeological monuments with high accuracy, especially in countries exposed to acts of sabotage resulting from wars and conflicts or highly exposed to natural disasters such as earthquakes, in addition to rising sea levels resulting from global warming. Therefore, accurate and complete digital documentation is a prerequisite for further analysis, interpretation and monitoring to predict any potential risk in the future. In this particular study, the historical sea castle in Sidon, Lebanon, was surveyed using GPS instruments, a 3D laser scanning device, and an aerial survey conducted by a traditional imaging drone. After the data was analysed and processed, two 3D models were created for the site. The model generated through terrestrial laser scanning exhibited a high level of accuracy compared to the model produced through aerial photogrammetry. However, by applying the ICP method with the Agisoft Metashape software, the accuracy of the aerial photogrammetric model was enhanced, resulting in a comprehensive 3D model that covers the entire castle.

Keywords: 3D Laser Scanning, 3D Model, GNSS, Photogrammetry

1. Introduction

The rapid technological advancements in recent years have revolutionized the field of mapping and spatial documentation, transitioning from traditional methods to modern techniques like 3D modeling and digital documentation [1][2] and [3]. These new technologies offer numerous benefits, such as reducing physical labor and emphasizing technical proficiency for tasks like data processing and analysis [4][5] and [6]. By employing modern methods for metric documentation and analysis of historical sites, the accuracy and quality of data can be significantly enhanced [7][8] and [9]. The use of 3D models provides a wealth of new features compared to traditional approaches, offering a more comprehensive representation of archaeological sites [10][11] and [12]. Furthermore, the generation of complex models from point cloud data enables the creation of high-quality Building Information Modeling (BIM) models for archaeological sites, incorporating new parameters for enhanced analysis [13][14] and [15]. Under climate change, sea levels have very diversified trends in many places like Mediterranean Sea, where the extreme water level can double [16][17] and [18].

This change of sea levels has a direct impact on small islands which are facing the danger of disappearing. Some studies predict that height of water level will continue changing to reach an increase of 0.8m in year 2066 [19][20] and [21]. The Middle East, known for its rich historical and archaeological heritage spanning thousands of years, faces ongoing risks to its archaeological sites due to conflict, wars and unrest. Despite efforts to protect these sites, a substantial amount of archaeological data continues to be lost, underscoring the urgent need for creating 3D models and digital archives to preserve and document this invaluable heritage, including sea castles and ancient ruins [22][23] and [24]. By leveraging advanced technologies and digital tools, we can safeguard and celebrate the cultural legacy of the Middle East for future generations.

When it comes to documenting archaeological buildings, both 3D terrestrial laser scanning and aerial photogrammetry offer unique benefits and advantages. 3D terrestrial laser scanning provides exceptional accuracy and detail when capturing the intricate features of archaeological structures up close.

This method allows for precise measurements and high-resolution 3D models, making it ideal for capturing fine details and textures of ancient buildings. However, terrestrial laser scanning may face limitations in terms of coverage, especially in inaccessible or hard-to-reach areas within the archaeological site. On the other hand, aerial photogrammetry offers a broader coverage by capturing images from above, enabling the efficient mapping of large archaeological sites and buildings, including inaccessible zones that are challenging to reach with terrestrial scanning equipment. The choice between these technologies ultimately depends on the specific requirements of the archaeological project, with both methods offering valuable tools for documenting and preserving archaeological buildings.

The research project involves utilizing aerial photogrammetry and terrestrial 3D laser scanning techniques to enhance the accuracy and detail of archaeological building documentation. By merging both models using software-based tools such as the Cloud to Cloud Distance tool and the Iterative Closest Point tool, the aim is to improve the accuracy of the photogrammetric model by incorporating high-resolution details captured by the laser scanning data. This approach showcases the effectiveness of integrating multiple data sources and advanced tools to create more precise and comprehensive documentation of archaeological structures, thereby contributing to the advancement of archaeological research and preservation efforts.

2. Material and Methods

In the article referenced [25], the authors discussed the impacts of climate change on archaeological buildings including coastal ones, emphasizing the importance of increased research in this area as recommended by the UNESCO World Heritage Centre. Various modern geodetic techniques could be applied to model and monitor historical and archaeological buildings such as (i) geodetic measurements of vertical displacements, (ii) geodetic measurements of horizontal displacements, (iii) terrestrial laser scanning, (iv) close range photogrammetry and (v) unmanned aerial vehicles (drones) [26][27] and [28].

Nowadays it is preferred to use laser scanners for this purpose, where the documents made in this way are easy to preserve, can understand the surface in detail, and can provide timely and accurate restoration and recovery data when buildings are damaged [31] and [32]. To monitor deformation assessment, studies and analysis are carried using three main approaches: 1) Point to Point, 2) Point to Surface and 3) Surface to Surface [33] and [34].

Processing of virtual restoration consists of managing big data; some practical solutions can reduce file sizes, by reducing the amount of polygons in the3D model; for temporary work files the high reduction can be executed, but to seek a compromise between workability and minimal impact on the resolution of the 3D model a small reduction should be conducted [35]. The collected data of terrestrial laser scanning in this study was developed in the program Leica Cyclone 3D which offers different operations: orientation of point clouds, clearing the composite image, unification and mesh creation [36].

On another hand, photogrammetric methods can be used to build models when high precision is not necessary; the main characteristic of this method is the textured model (color, invoice). By utilizing affordable digital cameras and software available on personal computers, it is now feasible to construct comprehensive digital models, resulting in cost and time savings. This approach does not necessitate specialized imaging expertise as laser scanning does. However, it is important to adhere to the guidelines for capturing multiple images for the purpose of Photogrammetry. An example of computer software for processing photogrammetric data is the Agisoft as used in this study; some studies show its reliability and validation in the triangulation process and 3D modelling applications in addition to the generation of surfaces from 3D data for accurate modelling using the kriging interpolation method. It also has a great potential to intensify points during triangulation process without the need of approximate values to the unknowns including the exterior orientation parameters and the control points.

In another article referenced [37], the authors used two different methods to generate 3D point clouds on different object materials and accuracy of distance measurements generated by iPhone 12 Pro were used as the parameters of quality assessment while comparison to terrestrial laser scanning served as reference data and found that the output of 3D model generated from iPhone LiDAR Sensor is sufficed to replicate the 3D indoor building environment but limited to small coverage area.

The authors have compared results and checked the accuracy but the study didn't consider the possibility of using approaches based on computer principles to increase the accuracy of a final combined model, and this is what is proven in this study but using the terrestrial laser scanning and aerial photogrammetry, since in archaeological purposes, a system with a relatively high accuracy is required; thus it is important to choose an instrument capable of detecting the geometric variation present in a given characteristic [29] and [30].

Before starting any mission, it is important to investigate the site and its surroundings to determine the necessary positions of the scanner and the targets, ensuring that the acquired data will represent the complete measured area and reducing as much as possible the amount of original data; at this stage it is necessary to establish an accurate control network in the site and this requires the use of the global navigation satellite systems GNSS with the help of other instruments like total stations in case of indoor measurements and low sky visibility.

2.1 The Case Study 'Sidon Sea Castle'

Lebanon is a Middle Eastern small country located at the eastern basin of the Mediterranean Sea. Its location made it a land where many civilizations settled and developed thousands of years ago leaving ancient monuments and fortresses of great historical importance. Sidon is one of the ancient Phoenicians cities and has been of great historical value, inhabited since 4000 B.C. In the 13th century the Crusaders built a castle on a small island dominating the sea, this island was previously a Phoenician temple connected to the mainland by a narrow 80 m long pier built on nine arches. In 2018 parts of the southwestern section of the site broke off and the damaged area was closed for 70 days. The Figure 1 shows an image for the castle from the pier connecting it to the mainland. The aerial view of the castle with its surrounding is shown in Figure 2.

Figure 1: The pier leading to the entrance of Sidon sea castle

Figure 2: An aerial image of the Sidon sea castle (in red circle)

2.2 Theory/Calculation

The adopted procedure for the work is shown as follows:

The initial phase involved conducting an exploratory visit to the site in order to gather information. Based on this visit, the fieldwork was planned, and the necessary equipment and techniques were determined, taking into consideration the potential challenges and obstacles that may arise during the survey. It is worth noting that the castle is situated on an island.

The subsequent step was to establish a precise control network both inside and surrounding the site. This was achieved by setting up multiple control stations, and the 3D coordinates of these stations were accurately measured. To accomplish this, two Topcon Hiper V GNSS receivers were employed in RTK mode, and a Topcon OS-103 total station instrument was used within the castle's rooms and halls where the GNSS receivers were not able to function correctly in these areas due to the lack of open sky visibility. The measurements done according to the local coordinates system named “Deir-Zor Levant Stereographic” established based on CLARCKE1880 Ellipsoid and adopted in the Lebanese territories; the total number of established stations was 23 and the reference station is a geodetic point located on the roof of the southern part of the castle. Those control points are distributed as follow: three points on the pier of Sidon national sea port, two points on the pier leading to the castle, one point on a rock located to the east of the site and the rest of the points are located in the castle. These control points will be used later either as occupation stations for the 3D laser scanner, or backsight points where the target should be placed and scanned during the setup stage before each scan, or as centers of the ground control points (GCP) which will be fixed on the ground before starting the flight stage for the photogrammetric mission.

Using some of these points as (GCP) for photogrammetry is a smart approach to aligning the resulting models in the same frame and coordinate system. This process is indeed essential for achieving accurate and reliable correlations between the two models. It is important to notice that all points are marked without causing any scratches or permanent paints in the site respecting the standards of the Ministry of Culture. The distribution of the control points in the site is shown in the map available in Figure 3. The coordinates of the control points are listed in the Table 1.

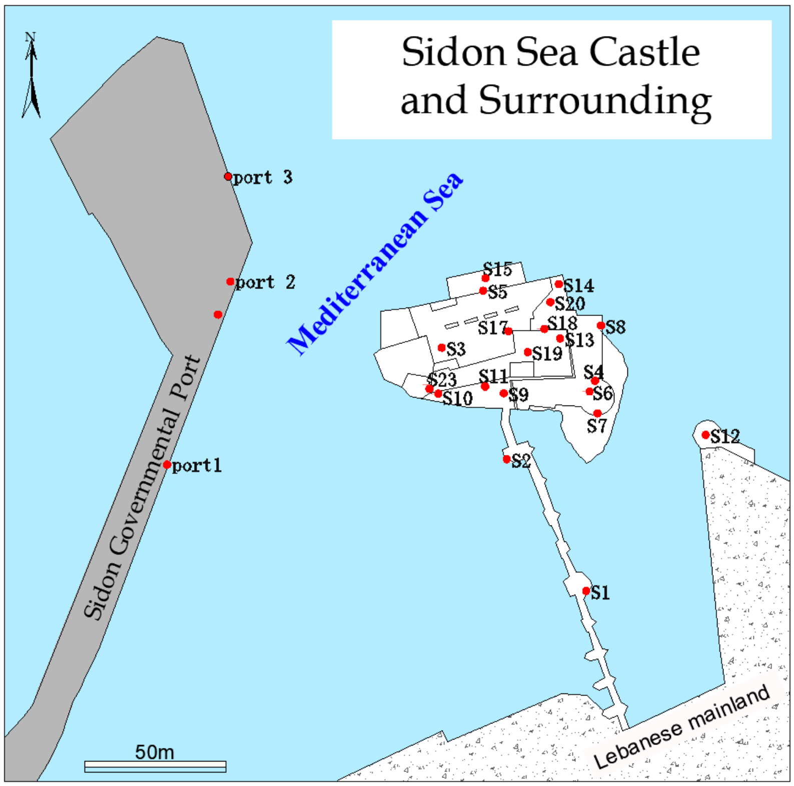

Figure 3: Distribution of control points

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Table 1: The list of control points fixed and measured in the site

Point #	Easting (m)	Northing (m)	Elevation (m)	Point Description
1	-350,809.428	-63,790.527	2.968	S1
2	-350,837.536	-63,743.856	2.803	S2
3	-350,860.511	-63,704.167	1.158	S3
4	-350,806.270	-63,715.995	1.817	S4
5	-350,845.873	-63,684.014	0.984	S5
6	-350,808.159	-63,719.792	2.121	S6
7	-350,805.380	-63,727.572	3.418	S7
8	-350,804.126	-63,696.383	0.913	S8
9	-350,838.569	-63,720.455	2.496	S9
10	-350,861.765	-63,720.487	3.128	S10
11	-350,845.275	-63,717.829	8.695	S11
12	-350,767.069	-63,735.210	2.790	S12
13	-350,818.649	-63,700.995	10.985	S13
14	-350,819.070	-63,681.698	10.008	S14
15	-350,845.056	-63,679.652	0.821	S15
16	-350,836.893	-63,698.342	3.114	S17
17	-350,824.219	-63,697.564	1.468	S18
18	-350,830.106	-63,705.820	3.126	S19
19	-350,822.085	-63,688.121	2.791	S20
20	-350,864.896	-63,718.820	18.825	S23
21	-350,957.800	-63,745.722	2.951	port1
22	-350,935.387	-63,680.781	3.246	port 2
23	-350,936.187	-63,643.542	4.120	port 3

2.3 The Aerial Photogrammetric Mission

The photogrammetric mission was done using Phantom 4 pro drone as shown in the Figure 4 equipped with GNSS sensor. The camera model is FC6310 and the resolution is 5472 x 3648. The focal Length is 8.8 mm and the pixel Size: 2.41 x 2.41 µm.

The mission duration was about 1 hour, capturing 65 images at 96.8m elevation above sea level; the overlapping between images is 70% covering an area of 0.0664 km². The ground Resolution is 2.39cm/pixel and the point density is 109 Points/m². The number of ground control points (GCPs) was five points (P1, P2, P3, P4 and P5) fixed respectively over the first five control points listed in Table 1; the Figure 5 shows a captured image of the GCP “P3” in the site. The captured images were processed using the ‘Agisoft Metashape’ software. The first operation was applying datum transformation from WGS84 to Local Datum by applying 7 transformation parameters, and then an Ortho-image is created. The Agisoft Metashape software calculates errors in Ground Control Points (GCPs) as seen in the Figure 6, where the color of the ellipses indicates the elevation error, while the dimension and shape of the ellipses represent the planar error. The errors were evaluated and adjusted based on the known coordinates of the GCPs, and the software allows then to enhance the precision and reliability of the final DEM and model outputs.

2.4 The Terrestrial Laser Scanning

The entire site was thoroughly scanned and photographed from ground level using a Leica P30 3D laser scanner instrument. The laser scanner was utilized by selecting the control network stations as occupation and back-sight points.

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Figure 4: Phantom 4 Pro drone equipped with the aerial camera

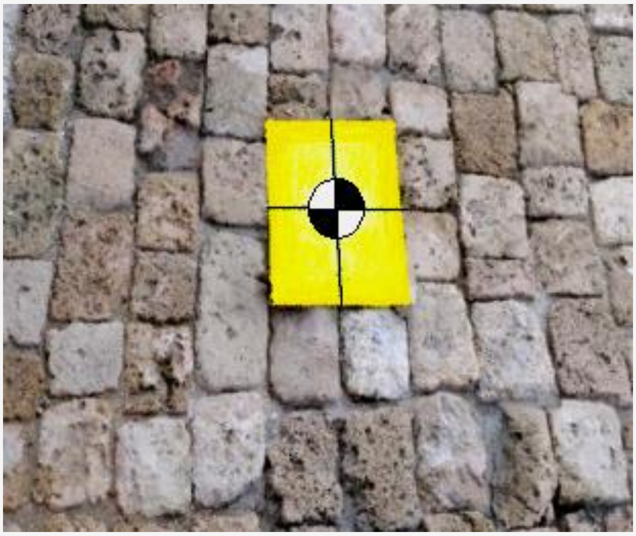

Figure 5: GCP size of 0.80 ×1.00 m

Figure 6: The Ortho-image for the castle created from aerial photogrammetric data

Through 13 scanning and imaging sessions carried out from various positions inside and around the site, the castle was comprehensively surveyed with exceptional detail. Figure 7 displays the arrangement of the laser scanner on the north-eastern side of the castle over the control point “S12”. The total number of collected points during the entire mission of scanning is 854815305; the details of each scan are shown in the Table 2.

During the scanning process in the field, the “Scanning and Imaging” option was selected. With this option, the 3D points for precise spatial information of the castle were efficiently collected while also assigning colors were assigned to enhance visual representation. Following the collection of field data, a substantial amount of data was extracted and processed using the Leica Cyclone software to generate the point cloud data. The 3D point cloud model in real colors provides a visually realistic representation of the site, allowing for easy identification and recognition of objects and features. This can be particularly useful for visualization purposes and for conveying a more accurate depiction of the environment, the Figure 8 shows the point cloud model for the castle in real colors. On the other hand, the 3D point cloud in intensity mode emphasizes the differences in reflectivity or intensity of the points, which can be valuable for applications such as object classification, feature extraction, and analysis of material properties; this mode can help in identifying subtle variations in the environment that may not be as easily discernible in real colors. The Figure 9 shows the point could data for the entrance of the castle in intensity mode.

Figure 7: The 3D laser scanner at the northeastern side of the castle

Table 2: The number of collected points in each scan

Scan Number	Number of collected Points
1	41,844,793
2	76,145,852
3	48,036,626
4	90,509,123
5	37,979,082
6	58,279,255
7	43,122,496
8	31,515,466
9	46,663,298
10	38,128,561
11	149,751,171
12	147,761,239
13	45,078,343

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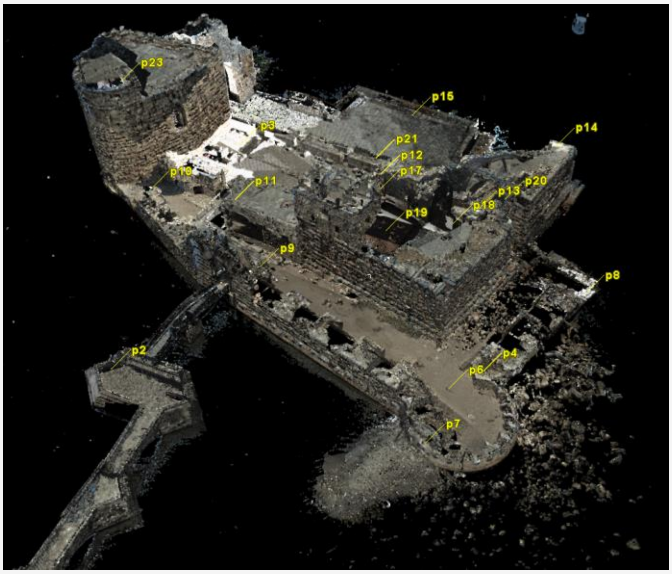

Figure 8: The 3D model of the castle displayed in true colors

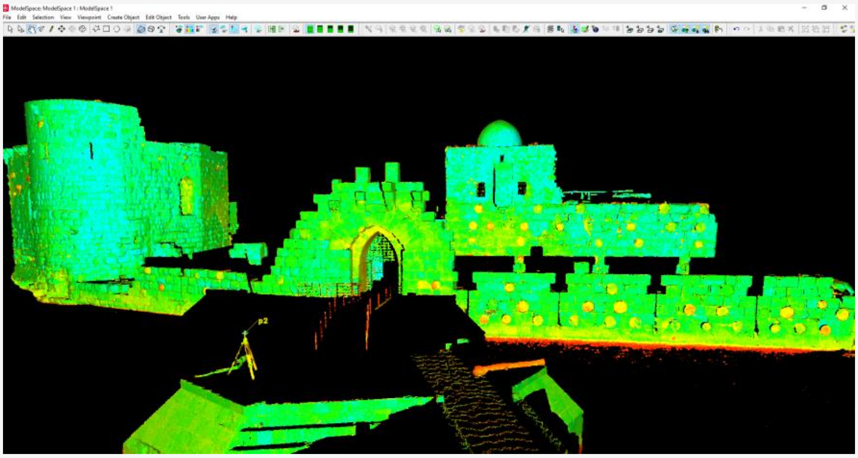

Figure 9: The 3D point cloud for the entrance of the castle displayed in intensity mode

3. Results

The two models generated by aerial photogrammetry and terrestrial laser scanning have different accuracy, obviously the terrestrial 3D laser scanning is more accurate and this is related to multiple factors. The benefit of the aerial photogrammetry is the data collection from above, which allow covering many inaccessible areas by terrestrial laser scanning especially the roofs. In this study, the data combination is applied for both models. The Cloud-to-Cloud Distance tool is applied using "CloudCompare" software which generally deals with huge point cloud data, the two models are integrated into the software and the Cloud-to-Cloud Distance was applied by selecting the model generated by terrestrial laser scanning as reference for the aerial photogrammetric model. When using the Cloud to Cloud Distance tool, the software compares each point in one point cloud to the closest point in another point cloud. By calculating the distance between corresponding points in the two clouds, the tool can provide information on the spatial differences or discrepancies between the two datasets. This analysis helps in assessing the alignment, accuracy, and registration of multiple point cloud scans, which is crucial for creating accurate 3D models or reconstructions. The result of computation of the two models by cloud/cloud Distance is shown in the graph in Figure 10. As shown in the figure above, the largest distance between the point clouds is 4.43m (left side) but the majority of the points are within a distance of 30cm (right side histogram).

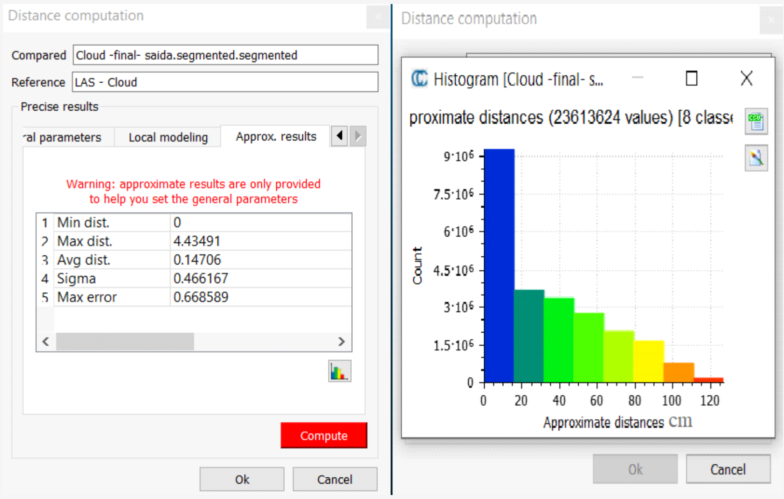

Figure 10: Cloud-to-Cloud distance computation results and histogram

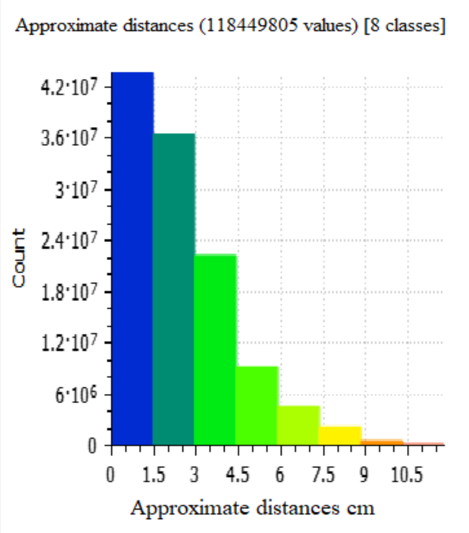

Figure 11: ICP tool results and histogram

The 2nd step was done also using 'CloudCompare' by increasing the subsampling density where a denser point cloud with more points is generated, then by applying the ICP (Iterative closest point) method where the registration error decreases slowly. This method works by iteratively refining the transformation (translation and rotation) between the two point clouds until a good alignment is achieved. This process involves finding the closest points in one cloud to points in the other cloud, calculating the transformation that minimizes the distances between these corresponding points, and then applying this transformation to one of the point clouds. This iterative process continues until the alignment error is minimized. Overall, ICP is a powerful tool for registering and aligning point clouds in various applications such as 3D reconstruction, robotics, and computer vision. The model generated by laser scanning was selected again as reference for the photogrammetric model and the results are shown in the Figure 11.

As shown in the figure above, the majority of the points after using the ICP tool are within a distance of 1.5cm indication a high increase in the accuracy of the aerial photogrammetric model if we compare it with the accuracy obtained when applying the Cloud-to-Cloud Distance tool. Based on the results of the ICP, the root mean square (RMS) error based on 50000 check points was calculated for the final combined model and evaluated as 1.37cm. Overall, a value of 1.37cm is likely a reasonable and acceptable result and meets the necessary level of accuracy for this particular project, this 3D model is shown in the Figure 12.

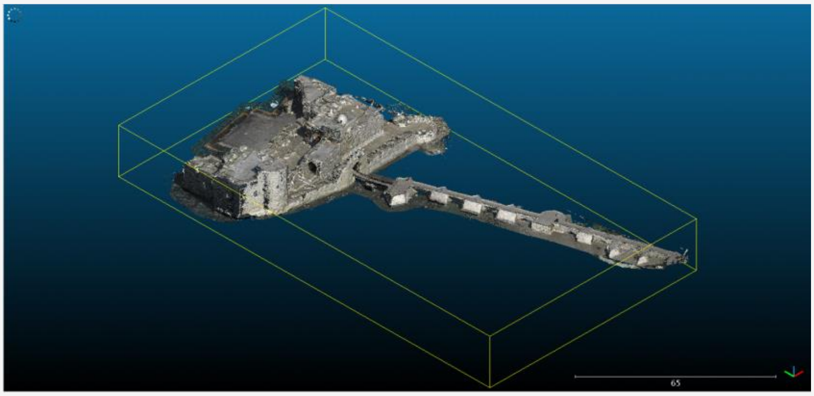

Figure 12: The final 3D model of the castle

4. Conclusion

In conclusion, the successful integration of terrestrial laser scanning (TLS) and photogrammetry techniques has enabled the creation of a highly accurate 3D model for Sidon Sea castle. This combined model showcases the potential of leveraging multiple technologies to achieve comprehensive and precise representations of historical landmarks. In addition, it is crucial to highlight that the sea castle has been fully documented through the meticulous process of creating the 3D model using TLS and photogrammetry. This comprehensive documentation not only preserves the historical significance of the castle but also provides valuable insights for future research, conservation efforts, and educational purposes. The importance of thorough documentation cannot be overstated, as it ensures the preservation and accessibility of cultural heritage for generations to come.

From another perspective, the accuracy of 3D models generated using medium accuracy platforms and sensors could be improved if combined with high accuracy 3D models usually generated by professional instruments like terrestrial laser scanners. One of these tools is the iterative closest point applied in this study which increased the accuracy of the majority of the points generated by aerial photogrammetry. In addition, the combination of terrestrial and aerial photogrammetry leads to a full site survey by covering the entire area of study even from above. Also, it is necessary to note that the accuracy of the established control network in the site by GNSS technologies and total stations is an essential factor for determining the accuracy of the generated models.

In the study of TLS and Photogrammetry of Sidon Sea castle, it's crucial to acknowledge limitations and suggest future research. Challenges arise in integrating data from different sources like TLS and Photogrammetry using tools like CloudCompare. Aligning and merging these datasets may introduce errors impacting the final model's accuracy. Despite efforts to validate individual models, uncertainties in data collection or processing methods could affect the merged model's precision. Future research could focus on refining data integration techniques and exploring alternative software for accuracy. Implementing a long-term monitoring plan to track changes in the sea castle could offer insights for conservation and historical documentation. Recognizing these limitations and suggesting future research can enhance findings in TLS and Photogrammetry.

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