Comparative Assessment of Archaeological Scene Reconstruction Using Iphone LIDAR Scanner

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iPhone, LiDAR, Point Cloud, Mesh, 3D Reconstruction, Archaeology

ABSTRACT

Archaeological sites hold immense economic value for Nepal, contributing to income and overall economic growth. These sites are susceptible to damage from both human activities and natural factors, needing swift and cost-effective reconstruction efforts. In addressing this challenge, 3D scene reconstruction emerges as a crucial reverse engineering method. Various techniques, such as LiDAR and Photogrammetry, are used for this purpose. While LiDAR offers precise models, its high cost has limited its accessibility. A notable development in this context has been achieved due to the introduction of consumer-grade LiDAR sensors, particularly with the integration of such sensors into iPhones. The primary focus of this research revolves around assessing the efficacy of consumer-grade LiDAR sensors in archaeological scene reconstruction. Utilizing the SiteScape and 3D Scanner apps, several tests with various settings were conducted to generate point clouds of the studied archaeological structures. The obtained point clouds were analyzed to assess point density variations across various application settings. Meshes were generated from these point clouds and the measurements were then taken from digital meshes which are compared with in-situ measurements, allowing for the calculation of relative error. Measurements obtained through SiteScape displayed a maximum difference of 4.17% and a minimum difference of 0.05%. In contrast, the 3D Scanner exhibited a maximum difference of 6.22% and a minimum difference of 0.09%. The findings suggest that the SiteScape app provides a higher point density and a higher accuracy than the 3D Scanner.

1. INTRODUCTION

Archaeology is the study of human cultures using material evidence to explain the origins and development of civilizations (Hussain & Will, 2021). Archaeological sites are subjected to deterioration due to natural calamities as well as anthropogenic causes (Linn, 2018) like air temperature (A. El-Gohary, 2010), wind erosion (Delgado Rodrigues & Gil Saraiva, 1985), earthquake (Ignatavičius & Ignatavičius, 2005). The historical monuments are of significant source of income and economic growth through national and international tourism in Nepal. Thus, it requires high-paced reconstruction but the process is generally delayed due to a lack of archaeological framework and manpower required to reconstruct traditional artifacts (KC et al., 2019).

3D model reconstruction is considered the most important information of reverse engineering required for the reconstruction of such sites (Intwala & Magikar, 2016). The image-based 3D reconstruction method has been used in reconstruction scenarios, including earthquake mitigation, construction monitoring, and the development of buildings (Han et al., 2022). The traditional method, image-based 3D reconstruction technique is time-consuming for the image processing, and its ability to effectively simulate situations has become a bottleneck that prevents it from being used in emergency situations (Han et al., 2022). Thus, the development of accessible and cost effective method to carry out the reconstruction of the archaeological framework has become necessary. Light Detection and Ranging (LiDAR) and Unmanned Aerial Vehicle (UAV) photogrammetric data capture are desirable over conventional survey due to their efficiency and accuracy over large areas (Jakovljevic et al., 2019; Khanal et al., 2020; Kovanič et al., 2023)

A single narrow-beam laser and a receiver system make up a LiDAR system. An optical pulse created by the laser is transmitted, reflected by a target, and then sent back to the receiver. The receiver measures the pulse's complete travel time, from the beginning to the end calculating the distance between launches, and determining the 3D coordinates of locations (Pajankar et al., 2019). LiDAR is a powerful tool to help uncover possible archaeological structures and its reconstruction. Therefore, it is possible to obtain a 3D reconstruction based on LiDAR data(Cheng et al., 2013; Forlani et al., 2006; Khanal et al., 2020; Wu et al., 2018). Nevertheless the high cost (in the range of 60k-80k €) of such integrated LiDAR systems makes their regular use only possible for very large projects (Zaczek-peplinska & Kowalska, 2022).

In 2020, Apple Inc. released the first phone with integrated built-in LiDAR depth sensors and an improved augmented reality (AR) application programming interface (API). In order to compete with the existing hardware solutions for survey operations requiring just moderate accuracy, a comparatively cheap alternative was devised. Nonetheless, in Archaeological sector, the use of iPhone's LiDAR performance and precision of the acquired 3D point clouds has not been very well studied and documented (Teppati Losè et al., 2022). Thus, this study aims to address the gap and analyze the effectiveness of the consumer grade LiDAR in archaeological scene reconstruction.

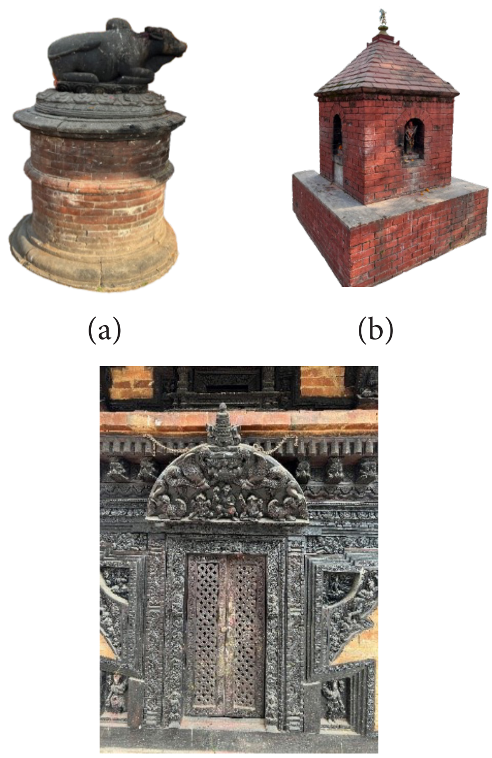
The main objective of the study was to evaluate the efficacy of iPhone's LiDAR in documenting the 3D structure for archaeological scene reconstruction. Additionally, the study aimed to compare scanning apps; SiteScape & 3D Scanner. The different scanning modes offered by the selected apps were also studied.

2. MATERIALS AND METHODS

2.1 Study Area

The archaeological structures were selected from the Panauti Municipality, Nepal. It is located 32 km southeast of the capital city, Kathmandu. The municipality has been listed as a probable site for UNESCO world heritage since 1996 (UNESCO, n.d.), which specifically concentrates on the reconstruction of archaeologically significant sites. Panauti being a historically important city consisted of a variety of Hindu and Buddhist monuments of different sizes and surface complexities (UNESCO, n.d.). Archaeological structures selected are shown in Figure 1.

Three structures based on the type of structures were selected for this study. The structure types for the monuments include stone surface, brick surface, and wooden carved surface. The study structures were categorized as case study 1, case study 2, and case study 3 for combination of stone and brick structure, brick structure and carved-wooden structure respectively.


(a) (b)

(c)

Figure 1: Study Structures a) Combination of stone and brick, b) Brick structure c) Carved-wooden structure

2.2 Methods

The major stage of the methodology were: Data Capturing, Data Collection, Data Preparation, and Data Analysis. The study was carried out in three archaeological structures. b) They were scanned with the scanning apps which directly provided the point clouds. The point density is compared between the scanning apps. 3D mesh was also generated using the point clouds obtained. The dimension measurement (such as length, breadth and height) was carried out in the mesh and it was compared with the in-situ measurements. Figure 2 shows overall methodological process of comparative assessment of archaeological scene reconstruction using iPhone's LiDAR.

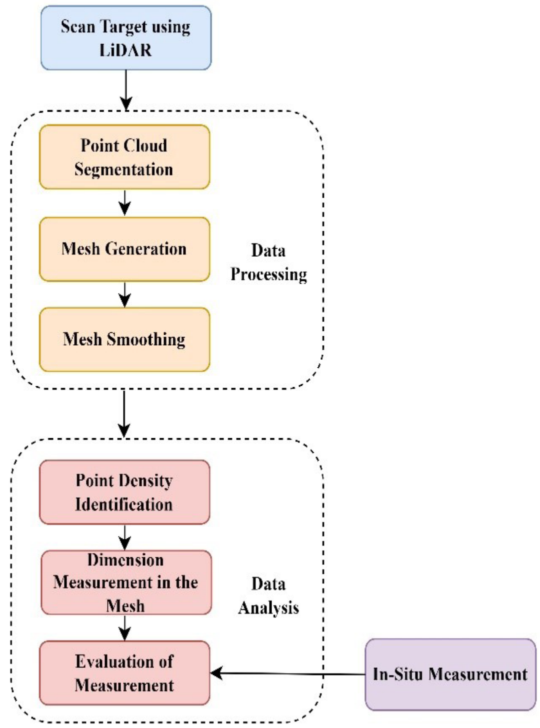


Figure 2: Methodological flowchart

2.2.1 Scan Target Using LiDAR

The applications SiteScape and the 3D scanner app which are available in iPhone 14 pro apple stores were utilized for the study. The iPhone was placed at a distance of 2-3 meters from the structure being scanned to capture the data. The scanning process involved moving the iPhone in a clockwise direction to cover the entire structure as shown in Figure 3.

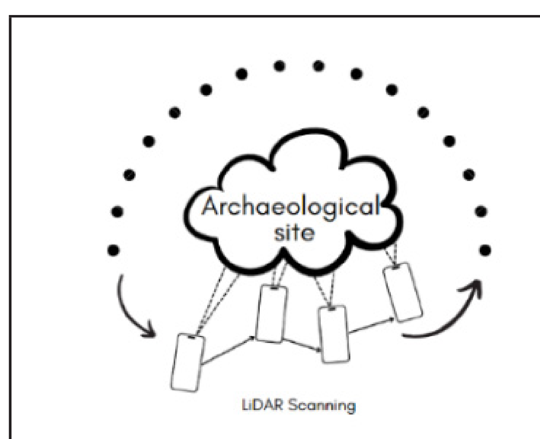


Figure 3: Data Collection process using LiDAR Method

The following settings were incorporated to collect the data from these applications:

Scan settings of SiteScape

- High Point Density, High point Size (SiteScape1)
- High Point Density, Low Point Size (SiteScape2)
- Low Point Density, High Point Size (SiteScape3)
- Low Point Density, Low Point Size (SiteScape4)
- Medium Point Density, Medium Point Size (SiteScape5)

Scan Settings of 3D Scanner

- Low Confidence, 5 mm Resolution (3D Scanner1)
- High Confidence, 5 mm Resolution (3D Scanner2)
- Medium Confidence, 5 mm Resolution (3D Scanner3)

2.2.2 Point Cloud Segmentation

The point cloud files were exported in .e57 format and .las format for the SiteScape and 3D Scanner App respectively which provided the point clouds data directly.

The point clouds obtained from both techniques were added in Cloud Compare software. The point clouds contained points that covered background noises. So, the clipping of point clouds was accordingly done to achieve only targeted structure.

2.2.3 Mesh Generation

Mesh was generated from the obtained point clouds. The normal tools and Poisson surface reconstruction plugin was used to generate the mesh.

The normal tool calculates point cloud's normal as it represented the local surface of that point and its neighbors. The model was first put through this process since the amount of noise and the number and proximity of neighboring structures could alter how this surface appears in the final model.

Poisson surface reconstruction plugin was used to generate the mesh. In Poisson surface reconstruction, main parameter was “Octree Depth” as the deeper (i.e. greater) the value, finer will be the result, but requires more time and memory.

In the next step, Input Density as SF operation was done in Cloud Compare which facilitates removing unnecessary portion from the previously generated mesh.

2.2.4 Mesh Smoothing

The generated mesh was smoothen to make the mesh finer in visual appearance. To smoothen the mesh generated, Laplacian smoothing tool was used. In this, value 20 was provided for iteration and 0.2 for smoothing factor.

2.2.5 Point Density Identification

The point densities in a specific portion of the structures, such as a 1m x 1m area in case Study 2, Case Study 3 and the upper part of the case study 1 was clipped as shown in Figure 5 and studied. The results for point density are presented in the results section.

2.2.6 Dimension Measurements in the Mesh

Measurements were initially taken on the ground using a measuring tape. The same measurements were replicated on a digital mesh, employing a "point picking" tool to determine distances between two points. To ensure accuracy, the average of measurements was calculated for both length and height.

2.2.7 Evaluation of the Measurements

The measurements obtained from the mesh were compared with the in-situ measurements. Following relation was used to compute the relative error percentage:

Relative Error (R.E.) in %

$$\frac{\textit{InSitu Measurement-Measurement made on mesh}}{\textit{InSitu Measurement}} * 100\%$$

3. RESULTS AND DISCUSSION

3.1 Result

The mesh of the each structures were obtained as depicted in Figure 4. The point density in different scan settings were studied and also the difference in the dimension measured between in-situ measurements and the measurements achieved from mesh were studied.

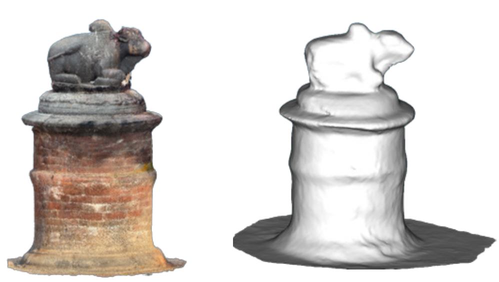
3.1.1 Mesh of the Structures

Sample representations of the generated meshes are shown in Figure 4 for each of the archaeological structures. The parameters that were used to generate the mesh has been shown in below in Table 1.

Table 1: Parameters for mesh generation

Plugins	Parameters	
Normals	Local Surface Model	Plane
	KNN Value	8
PoissonRecon	Octree Depth	10

The meshes generated from SiteScape data displayed RGB color, while those from the 3D Scanner App lacked RGB color and were initially rendered in green. Subsequently, a color scale with intensity values ranging from 0 to 1 is applied to represent the meshes in white hues.



(a) (b)

(c) (d)

(e) (f)

3.1.2 Point Density Comparison

Application	Settings	Point density (upper part of sculpture, Figure 5)
SiteScape	SiteScape1	6808918
	SiteScape2	5654703
	SiteScape3	3065422
	SiteScape4	1870084
	SiteScape5	3710338
3D Scanner	3D Scanner1	16329
	3D Scanner2	15300
	3D Scanner3	14912

The first analysis done on this study was comparison of the point density in the point clouds obtained using different settings SiteScape1, SiteScape2, SiteScape3, SiteScape4, SiteScape5, 3D Scanner1, 3D Scanner2, and 3D Scanner3.

The density of points in different scanning modes of the SiteScape application varied for the same structures. Similarly, the point density obtained from 3D Scanner had lower point density compared to SiteScape. The following sections briefly describes the point density comparisons in different case studies.

Case Study 1: Combination of stone and brick

Figure 5: segmented point cloud of Case Study 1: SiteScape (Left), 3D Scanner (Right)

The case study 1 corresponds to the Stone Sculpture (Nandi) which was constructed using stone. A stone was skillfully carved to create a sculpture of Nandi, which is a significant figure in Hindu culture as the mount of Lord Shiva. The stone sculpture exhibits fine texturing and detailing. However, during the segmentation process for this structure, the desired dimensions of 1m*1m were not achieved. Consequently, the upper part of the sculpture was separated, as illustrated in the Figure 5. It's worth noting that the segmentation was uniformly applied across all scanning modes.

Table 2: Comparison of Point Density of Case Study 1 in different scan mode

Application	Settings	Point density (upper part of sculpture, Figure 5)
SiteScape	SiteScape1	6808918
	SiteScape2	5654703
	SiteScape3	3065422
	SiteScape4	1870084
	SiteScape5	3710338
3D Scanner	3D Scanner1	16329
	3D Scanner2	15300
	3D Scanner3	14912

When analyzing point density, SiteScape outperformed the 3D Scanner in terms of providing a denser point cloud. Among the different scanning settings, SiteScape1 yielded the highest number of points, while SiteScape4 produced the lowest point count. On the other hand, within the 3D Scanner data, 3D Scanner1 generated the most points 16,329 while 3D Scanner3 produced the fewest points.

Case Study 2: Brick structure

The case study 2 corresponds to the Indreshwor temple which was constructed using bricks, and small stone sculptures of the goddess were placed inside the temple. Firstly 1m*1m area was segmented from the existing point cloud to identify point density. When examining the point density, in various settings using SiteScape and 3D Scanner, the following outcomes were observed. SiteScape1 offered the highest point density, while SiteScape3 had the lowest point density. Notably, the 3D Scanner only produced point densities in the thousands. 3D Scanner2 yielded a higher density of points, whereas 3D Scanner1 produced the lowest point density. In comparison to the SiteScape app, 3D Scanner provided much less point density in 3 different settings.

Table 3: Comparison of Point Density of Case Study 2 in different scan mode

Application	Settings	Point density (per sq. m)
SiteScape	SiteScape1	1738367
	SiteScape2	1525050
	SiteScape3	340808
	SiteScape4	911772
	SiteScape5	723185
3D Scanner	3D Scanner1	8462
	3D Scanner2	8706
	3D Scanner3	8511

Case Study 3: Carved-wooden structure

The case study 3 corresponds to the wooden carved door. Firstly 1m*1m area was segmented from the existing point cloud to identify point density. In this case as well, SiteScape has resulted far denser points than that of 3D Scanner. The result shows that the SiteScape2 has maximum point density that accounts for 1688775 points while SiteScape3 provided the least point density. Studying the point densities from the 3D Scanner, it shows the point densities again in only thousands. Maximum point density was achieved in 3D Scanner1 and least point density has been obtained in 3D Scanner3.

Table 4: Comparison of Point Density of Case Study 3 in different scan mode

Application	Settings	Point density (per sq. m)
SiteScape	SiteScape1	692455
	SiteScape2	1688775
	SiteScape3	397468
	SiteScape4	699230
	SiteScape5	1185659

3D Scanner	3D Scanner1	9544
	3D Scanner2	8868
	3D Scanner3	8373

3.1.3 Evaluation of the dimension measurements

Second analysis done in this research was comparison of the measurements in different settings of the scanning apps, SiteScape1, SiteScape2, SiteScape3, SiteScape4, SiteScape5, 3D Scanner1, 3D Scanner2 and 3D Scanner3. The measurements done in the mesh using point picking tool was compared with the in-situ measurements. The measurements obtained from in-situ and computed from mesh are shown in Table 5, Table 6, Table 7 along with the relative errors found in the measurements from the mesh.

Case Study 1: Combination of stone and brick

The assessment of the case study 1 included using a tape measure to measure both the circular section and height, yielding a circumference (CF) of 3.28 meters and a height (H) of 1.05 meters.

Following this, within the mesh created from point clouds obtained from both applications, multiple measurements of the same dimensions were measured. The average of the multiple measurements were calculated and are presented in Table 5 along with the relative errors in the measurements.

Table 5: Comparison of dimensions of digital meshes with in situ measurements of Case Study 3

Measurement Modes	CF (m.)	H (m.)	R.E. of CF (%)	R.E. of H (%)
In Situ Measurements	3.28	1.050	-	-
SiteScape				
SiteScape1	3.159	1.020	3.67	2.85
SiteScape2	3.264	1.024	0.48	2.44
SiteScape3	3.260	1.023	0.60	2.56
SiteScape4	3.245	1.034	1.07	1.52
SiteScape5	3.143	1.024	4.17	2.52
3D Scanner				
3D Scanner1	3.136	1.024	4.38	2.46
3D Scanner2	3.127	1.006	4.67	4.21
3D Scanner3	3.076	1.014	6.22	3.48

The results clearly show that SiteScape provides greater accuracy in comparison to the 3D Scanner application. When evaluating circumference measurements, SiteScape2 displayed the highest accuracy with only a 0.48% error, while 3D Scanner3 exhibited the largest error at 6.22%. Regarding height measurements, SiteScape4 demonstrated the least error, specifically 1.52%, whereas 3D Scanner2 showed the highest error at 4.21%.

Case Study 2: Brick structure

In this case, length and height were measured by using tape which resulted in 1.832 meter length and 1.067 meter height.

Following table provides the comparison of the measurements with in-situ measurements.

Table 6: Comparison of dimensions of digital meshes with in situ measurements of Case Study 2

Measurement Modes	Length (m.)	Height (m.)	R. E. of length (%)	R. E. of height (%)
In Situ Measurements	1.832	1.067	-	-
SiteScape				
SiteScape1	1.827	1.065	0.27	0.19
SiteScape2	1.834	1.064	0.11	0.28
SiteScape3	1.831	1.068	0.05	0.09
SiteScape4	1.817	1.054	0.82	1.22
SiteScape5	1.829	1.062	0.16	0.47
3D Scanner				
3D Scanner1	1.768	1.061	3.49	0.56
3D Scanner2	1.849	1.065	0.93	0.19
3D Scanner3	1.809	1.068	1.26	0.09

The results clearly indicate that SiteScape offers superior accuracy compared to the 3D Scanner application. When evaluating length measurements, SiteScape3 displayed the greatest accuracy with a mere 0.05% error, and SiteScape4 exhibited highest at 0.82%, while 3D Scanner1 showed the highest error at 3.49%. Regarding height measurements, SiteScape3 exhibited the least error at 0.09%, whereas 3D Scanner1 demonstrated the highest error at 0.56%.

Case Study 3: Carved-wooden structure

In this case, length and height were measured using tape which resulted in 2.57 meter length and 1.312 meter height.

Following table provides the comparison of the measurements with in-situ measurements.

Table 7: Comparison of dimensions of digital meshes with in situ measurements of Case Study 3

Parameters	Length (m.)	Height (m.)	R.E. of Length (%)	R. E. of Height (%)
In Situ Measurements	2.57	1.312	-	-
SiteScape				
SiteScape1	2.568	1.311	0.06	0.05
SiteScape2	2.559	1.316	0.44	0.33
SiteScape3	2.567	1.310	0.12	0.14
SiteScape4	2.572	1.310	0.09	0.19
SiteScape5	2.560	1.320	0.39	0.60
3D Scanner				
3D Scanner1	2.551	1.284	0.73	2.16
3D Scanner2	2.552	1.283	0.71	2.18
3D Scanner3	2.551	1.288	0.73	1.83

This results clearly indicates that SiteScape provide better accuracy compared to the 3D Scanner application. When evaluating length measurements, SiteScape1 displayed the highest accuracy with only a 0.06% error, while 3D Scanner1 and 3D Scanner2 exhibited the largest error at 0.73%. In terms of height measurements, SiteScape1 demonstrated the least error, specifically 0.05%, and the highest error at 0.60%, while 3D Scanner2 showed the highest error at 2.18%.

3.2 Discussion

In this study, we examined two distinct LiDAR apps by generating mesh using various modes within those applications and subsequently comparing their dimensions with in-situ measurements. The relative error in accuracy assessment was affected by discrepancies in point selection, as different individuals marked distinct points while evaluating the mesh dimensions. This introduced uncertainty in the measurements in the mesh, also the results varied based on the textures and materials of the structures under consideration which is in alignment with (Kovanič et al., 2023).

The primary difficulties associated with employing the iPhone's LiDAR approach lie in the data acquisition phase, where the obtained point clouds exist in an arbitrary coordinate system. Despite having location services enabled during data acquisition, it did not impart any location information, leading to the use of an arbitrary coordinate system. Even though the data captured was in arbitrary coordinate system, it did not affect the accuracy drastically. Additionally, capturing detailed information about the upper parts of structures with greater heights proved challenging with the iPhone. Consequently, point clouds may not be generated for the upper section of monuments, resulting in the creation of voids in the mesh. Mokroš et al., (2021) highlight the potential of Apple's technology for scanning geomorphological formations, but also identify several issues and challenges. Mokroš et al., (2021) emphasize the importance of data collection methods in ensuring its completeness. The Apple device's scanning distance was less than 3 m, compared to terrestrial laser scanners that can reach up to 200 m. This is a significant limitation to the technology's use.

It was found that the higher number of point density was obtained from SiteScape's point cloud rather than the point clouds of 3D Scanner is in alignment with the result obtained in (Vacca, 2023). SiteScape achieves this by conducting repeated acquisitions in the same area, thereby increasing the number of points observed. Meanwhile, 3D Scanner provided least number of point clouds as 3D Scanner app does not increase the number of points when the operator scans the same area multiple times, resulting to a less noisy point cloud (Teppati Losè et al., 2022). The limited points in the 3D scanner's point cloud contributed to a less accurate results.

The result above signifies SiteScape app offers superior geometrical accuracy as the measurements provide the precise results than the 3Dscanner app (Kartini et al., 2022). However, the meshes generated through SiteScape app are visually appealing due to the inclusion of RGB values providing colored textures, and displaying distinct variations in texture and intricate patterns carved in the monuments. However, the mesh generated exhibit blurriness, making it challenging to achieve a clear visualization of the study area. On the other hand, the meshes obtained from the 3D Scanner app appear less sharp and lack the actual color representation as the object was scanned for a longer duration for covering the whole scene of monuments (i.e., no RGB values), reducing their suitability for visualization purposes in scene reconstruction.

Despite the SiteScape app providing superior accuracy, the dimensions from meshes generated by both applications do not deviate significantly from the in situ measurements. The analysis suggested that both applications produced sufficiently significant outcomes, making them suitable for practical modeling for scene reconstruction. (Vacca, 2023) findings suggest that Apple LiDAR sensors are a valuable tool for creating 3D models of architectural and cultural heritage, contributing to metric documentation and asset knowledge. This match with the results obtained in the context of archeological scene reconstruction.

4. CONCLUSION AND RECOMMENDATION

The main goal of this research was to compare the consumer grade LiDAR sensor and its usability for reconstructing archaeological scenes. Both applications examined in this study allow for the direct export of generated point clouds and potential meshes in different formats. The iPhone's consumer-grade LiDAR, characterized by its accessibility, affordability, and user-friendly interface, becomes a convenient option for individuals with limited training, providing a simplified approach to scene reconstruction compared to Terrestrial Laser Scanning (TLS).

The study seeks to quantitatively evaluate commonly used apps and LiDAR devices, highlighting their potential benefits while identifying potential limitations. Although both apps demonstrated enhanced performance in diverse application scenarios, SiteScape consistently produced satisfactory reconstructions across all tested cases using the specified settings.

For future research, it is recommended to incorporate Ground Control Points (GCP) markers to improve point picking accuracy and minimize human errors. The inclusion of Model-to-Model comparison (M3C2 algorithms) in Cloud Compare could provide additional insights. Additionally, proposing a comparative analysis between Apple's LiDAR and TLS is suggested for the purpose of data validation and accuracy verification.

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