COMPARATIVE ANALYSIS OF POINT CLOUDS ACQUIRED FROM A TLS SURVEY AND A 3D VIRTUAL TOUR FOR HBIM DEVELOPMENT

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ABSTRACT:

This paper presents a comparative analysis of point clouds acquired from a terrestrial laser scanner (TLS) survey and a 3D virtual tour using Matterport technology for heritage building information modeling (HBIM) development. The study uses the Cloister of the Royal College of Corpus Christi Seminary, an important cultural heritage site in Valencia, Spain, as a case study. The point clouds from the TLS survey and Matterport scans were compared both quantitively in CloudCompare software and visually to assess their accuracy and quality. The Matterport point cloud data was found to be slightly lower in quality and accuracy compared to the TLS data, but still sufficient for developing some low-tolerance geometry in the HBIM model. The study shows that Matterport point cloud data has potential to supplement TLS scans, particularly in areas missed during the TLS survey due to range limitations. Matterport technology is accessible, affordable, and easy to use, making it a feasible option for heritage sites with limited resources. Moreover, Matterport technology captures high-quality visual data, including color and texture, providing a detailed representation of the heritage site. Thus, Matterport technology can be a valuable contribution to cultural heritage documentation and preservation, particularly for sites requiring a quick and efficient surveying process. The findings of this research offer insights into the relative advantages and limitations of these two reality capture techniques for cultural heritage documentation and preservation, and could potentially inform decision-making processes for future heritage preservation projects.

1. INTRODUCTION

The built heritage industry is facing significant challenges in the documentation, conservation, and management of heritage sites. Accurate, precise, and high-resolution data are required to acquire and preserve spatial and physical information of heritage sites. The traditional methods of surveying, such as manual measurements, drawings, and sketches, are time-consuming, expensive, and limited in the amount of information that can be captured (Jo and Hong, 2019; Themistocleous et al., 2016; Yilmaz et al., 2008). The development of new techniques in the field of remote sensing has revolutionized the way heritage sites are documented, and 3D point cloud data has become an essential tool in heritage documentation and management (Baik, 2017; Chen et al., 2019; Fregonese and Taffurelli, 2009).

Terrestrial Laser Scanning (TLS) is one of the most innovative techniques for the documentation of built heritage and has become mandatory for Historical Building Information Modelling (HBIM)) (Moyano et al., 2022b). TLS has been widely used in the domain of documentation and preservation of cultural heritage in the past decade due to its superior accuracy and high resolution (Martín-Lerones et al., 2021; Moyano et al., 2022a), speed over amount of data captured (Rocha and Mateus, 2021), and thoroughness of non-invasive object capture (Abbate et al., 2022; Franco et al., 2020) that does not require returned field survey and measurement (Palcak et al., 2022).

On the other hand, Structure from Motion (SFM) or photogrammetry technology (Andriasyan et al., 2020), ether terrestrial or aerial, has rapidly become another important technique for acquiring remote sensing point cloud data for HBIM (Abbate et al., 2022; Barrile et al., 2022; de la Plata et al., 2021; Reinoso-Gordo et al., 2018). The primary advantages of photogrammetry include its excellent ability to reproduce color and texture, and high accessibility and flexibility with equipment. It has become a standard practice to integrate TLS and photogrammetry together by exploiting the advantages of one over the other for data acquisition for HBIM (Costantino et al., 2021).

A collaborative research team comprising scholars from Spain and the United States conducted a case study on the documentation of the Cloister of the Royal College of Corpus Christi Seminary in Valencia, Spain. This cultural heritage site is a remarkable instance of Renaissance architecture in the city and a monument that exemplifies the Counter-Reformation in Spain (Llopis Verdú, 2007). The team used various Reality Capture (RC) techniques for the development of HBIM. Besides obtaining a large TLS point cloud from over three hundred scans, the team also captured an immersive 3D Virtual Tour (VT) and subsequently acquired another point cloud of the building from this VT. The time and resources used to capture the VT point cloud were significantly less than that to obtain the TLS point cloud.

The primary objective of this paper is to investigate the hypothesis that the VT point cloud data is sufficient for developing selected objects in an HBIM model, which may provide a quicker and more affordable method to supplement

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TLS survey. The findings of this research are significant in that they offer insights into the relative advantages and limitations of these two reality capture techniques for cultural heritage documentation and preservation, and could potentially inform decision-making processes for future heritage preservation projects.

2. LITERATURE REVIEW

Reality Capture (RC) techniques refer to a range of technologies used to capture and process data from the physical world to create digital 3D models. These techniques have been widely used in various disciplines, including architecture, engineering, and construction (AEC), and cultural heritage documentation and preservation. This chapter provides a review of the literature related to RC techniques for cultural heritage documentation and HBIM implementation, including TLS, photogrammetry, and Matterport. It includes an overview of the current state-of-the-art techniques, their strengths and limitations, and the emerging trends in this field. It also introduces the workflow of using data acquired from RC surveys to develop HBIM models.

2.1 Introduction to Reality Capture (RC) Techniques

Multiple innovative RC technologies have been embraced by researchers and practitioners to capture geospatial data of heritage structures. These techniques include Terrestrial Laser Scanning (TLS) (Y. Alshawabkeh et al., 2021; Dore and Murphy, 2017; Marzouk, 2020; VanValkenburgh et al., 2020), photogrammetry (Bagnolo et al., 2019; Baik et al., 2014), UAVs (Berrett et al., 2021; Carvajal-Ramirez et al., 2019; Ibrahim et al., 2022; Martinez-Carricondo et al., 2020), and 360-degree photography (Banfi et al., 2019; Barrile et al., 2022) among others. RC technologies accelerate data collection and reduce errors and deficiencies relative to the conventional method (Bastem and Cekmis, 2022).

2.1.1 TLS: TLS is a ground-based LiDAR (light detection and ranging) technology (“UNAVCO,” 2021) that use remote sensing measuring devices (a laser sensor) to collect dense point clouds of objects (Colombo and Marana, 2010). The point cloud generated from the scan can be used to create a highly accurate and detailed 3D model of the object. TLS is one of the most commonly used RC techniques for cultural heritage documentation, especially in the field of Heritage Building Information Modeling (HBIM), due to its superior accuracy, speed, and non-invasiveness. Yang et al. (2020) acknowledged in their review article that the utilization of TLS to capture point clouds of heritage structures has become an important tool for HBIM researchers and practitioners. However, TLS also has some limitations. It is incapable to capture occluded objects; sensitive to the environment such as lighting conditions, dust, fog, or rain (Palcak et al., 2022); and has trouble with shiny/reflective, black, and transparent surfaces. Moreover, the greatest limitations of TLS for HBIM are its resource-intensive hardware, software, and operator skill sets. TLS requires expensive scanners (Palcak et al., 2022), needs specialty software and highly trained professional to process and handle scan data (Y Alshawabkeh et al., 2021), and demands substantial hardware to handle the large scan datasets (Martín-Lerones et al., 2021). Although expedient for capturing sizeable and complex heritage sites, TLS necessitates an exponential amount of effort to process the scans, especially when capturing accurate colour with the built-in camera (Y. Alshawabkeh et al., 2021).

2.1.2 Structure from Motion (SfM)/Photogrammetry: Structure from Motion (SfM) or photogrammetry technology is another popular RC technique for cultural heritage documentation. It involves taking a series of overlapping photos from different angles and processing them to generate a 3D point cloud (Abbate et al., 2022; Barrile et al., 2022; de la Plata et al., 2021; Reinoso-Gordo et al., 2018). This technology has several advantages for cultural heritage documentation and preservation. It offers high accessibility and flexibility with equipment requirements, making it a cost-effective alternative to TLS (Rocha et al., 2020). It is also capable of capturing color and texture with high accuracy, providing a more complete representation of the object or site being documented. Additionally, photogrammetry can be used to capture data from a range of distances and angles, including aerial photogrammetry, which is useful for capturing larger heritage sites or difficult-to-access areas (Y Alshawabkeh et al., 2021). However, photogrammetry has some limitations in this field, such as its sensitivity to lighting conditions, which can affect the accuracy of the data, and the need for careful image acquisition and processing to ensure accurate 3D reconstruction (Cantó et al., 2022; Giżyńska et al., 2022).

2.1.3 Matterport: Matterport technology (Matterport, 2022) is a 3D scanning and Virtual Tour (VT) platform that has been increasingly used for cultural heritage documentation and preservation. The technology allows for the creation of immersive and interactive digital models of heritage sites, providing virtual access to these spaces for education, research, and tourism. Matterport technology has been applied to a variety of heritage sites, including museums, archaeological sites, and historic buildings. It is a user-friendly and affordable option for cultural heritage documentation and preservation, offering high-quality visual data capture, including color and texture, with minimal equipment requirements and accessibility, making it ideal for heritage sites with limited resources (Kocaturk et al., 2023; Liu et al., 2023; Liu and Willkens, 2021; Mazza et al., 2022; Shults et al., 2019).

Despite its advantages, Matterport technology has limitations that must be taken into account. These limitations include line-of-sight capture, difficulty with complex geometry and reflective/transparent surfaces, and lower accuracy compared to TLS or photogrammetry. Additionally, Matterport is sensitive to light conditions, has a limited range, and was previously incapable of capturing outdoor spaces until the release of its Pro3 camera. These limitations can affect the quality and accuracy of the digital model produced by the technology (Kocaturk et al., 2023; Mazza et al., 2022; Shults et al., 2019).

2.2 Heritage Building Information Modeling (HBIM)

Heritage Building Information Modeling (HBIM) is the process of creating digital 3D models of historic structures and buildings that contain both geometric and non-geometric information. The goal of HBIM is to provide a comprehensive and accurate representation of historic buildings that can be used for documentation, analysis, and preservation purposes (Murphy et al., 2013). A typical HBIM implementation workflow includes a preliminary phase to identify the purpose and determine the Level of Development (LOD), a data acquisition phase to capture spatial and semantic data, a data process phase, and a model development phase (Liu et al., 2023). The use of RC techniques for data acquisition for HBIM development has become increasingly popular due to their ability to provide accurate and detailed geometric information (Garcia-Gago et al., 2022; Liu et al., 2022; Murphy et al., 2013). The 3D models generated from RC techniques can be used to create digital twins of historic buildings, which can be used to simulate different scenarios and assess the impact of interventions or changes to the building.

2.3 Integration and Comparison of RC Techniques for HBIM Development

The integration of multiple RC techniques has become a standard practice in cultural heritage documentation, as it allows for the exploitation of the strengths of different techniques and compensates for their limitations (Andriasyan et al., 2020; Liu and Willkens, 2021). In their research, Costantino et al. (2021) surveyed a historic building in Italy using a combination of multiple RC techniques. The external façade was captured using TLS, while the inside was documented using a DSLR camera with a fisheye lens. The upper parts of the building, including the roof and other architectural elements not visible through a terrestrial survey, were captured using a camera mounted on an unmanned aerial vehicle (UAV) platform. Liu and Willkens (2021) documented the structural fabrics of the Old Depot Museum in Selma, USA using TLS, photogrammetry (terrestrial and aerial with a drone), and Matterport for the development of an HBIM model of this historic landmark.

Several studies have also compared the accuracy and efficiency of different RC techniques for cultural heritage documentation. Costantino et al. (2021) compared TLS and photogrammetry for the documentation and HBIM development of San Nicola in Montedoro church in Italy. The study found that while TLS provided the highest accuracy and precision, photogrammetry was more efficient and cost-effective. Moyano et al. (2022) compared the use of TLS and photogrammetry for the documentation of the Royal Palace of La Granja de San Ildefonso in Spain. The study found that the integration of both techniques provided the most accurate and detailed model of the building. In term of comparing Matterport with other remote sensing technologies, Chen et al.(2018) evaluated Matterport with 2 other indoor mapping tools for their accuracy, while Ingman et al. (2020) assessed Matterport with photogrammetry and a low-end Leica BLK360 laser scanner system. Both studies concluded that Matterport was more cost-effective but lacked accuracy. Table 1 summarizes the main characteristics of these 3 RC techniques for heritage documentation and HBIM development.

This research aims to contribute to the existing literature by presenting a case study of data acquisition for HBIM using TLS and Matterport and comparing the accuracy and completeness of the point clouds obtained using these two techniques, as well as assessing the potential for using virtual tours as a cost-effective alternative for capturing point cloud data for HBIM.

	Terrestrial Laser Scanning (TLS)	**Photogrammetry/SfM**	**Matterport Technology**
Accuracy	Typically sub-millimeter accuracy, can capture millions of points	Can achieve sub-centimeter accuracy depending on technique and equipment	Can achieve sub-centimeter accuracy depending on technique and equipment
Resolution	High resolution, can capture fine details	Lower resolution than TLS, can struggle to capture fine details	Lower resolution than TLS and photogrammetry
Speed	Slow data capture, can take several hours or days to complete a survey	Fast data capture, can cover large areas quickly	Fast data capture, can cover large areas quickly
Cost	High cost for equipment, software, and professionals	Lower cost than TLS, but still requires specialized equipment and software	Lower cost than TLS and photogrammetry, preferred to a Matterport Pro2 3D camera
Hardware Requirements	Requires specialized equipment, including laser scanners, tripods, and targets	Requires a camera and specialized equipment, such as a drone or tripod	Preferred to a Matterport Pro series 3D camera and tripod
Software Requirements	Specialized software for data processing, such as Faro Scene, Leica Cyclone, or CloudCompare	Specialized software for data processing, such as Agisoft Metashape or Pix4Dmapper	Matterport Capture App for capturing and automated cloud-based data processing (with required subscription for this cloud service)
Advantages	High accuracy and resolution, thorough non-invasive object capture	Good reproduction of color and texture, high accessibility and flexibility	Immersive experience for users, less time and resource intensive than TLS and photogrammetry
Limitations	Expensive hardware and software, requires highly trained professionals, limited to line of sight, sensitive to environmental conditions, resource-intensive data processing	Limited accuracy and resolution, sensitivity to environmental conditions, resource-intensive data processing	Limited accuracy and resolution, restricted to visible surfaces, potential for inaccuracies due to camera limitations, short range with any cameras other than the latest Matterport Pro3

Table 1. Key characteristics of the three data acquisition technique for heritage documentation and HBIM.

3. METHODOLOGY

3.1 Case Study Project

The Cloister of the Royal College of Corpus Christi Seminary, located in Valencia, Spain, serves as an ideal case study for this research project, as it represents a significant cultural heritage site with historical, artistic, and architectural value (Figure 1). Constructed in 1583 by Juan de Ribera, the building is considered one of the best examples of Renaissance architecture in Valencia and is a monument that best synthesizes the Counter-Reformation in Spain (Llopis Verdú, 2007). The building's design reflects the influence of architectural treatises, although a mimetic relationship has not been entirely maintained due to the refurbishment of some of its parts over time. The spaces of this large building form a highly complex architectural ensemble, and this plurality with significant spatial and decorative ornamentation makes it necessary to collect data using multiple data acquisition tools. The cloister, with its intricate architectural details, is one of the most significant spaces in the building.

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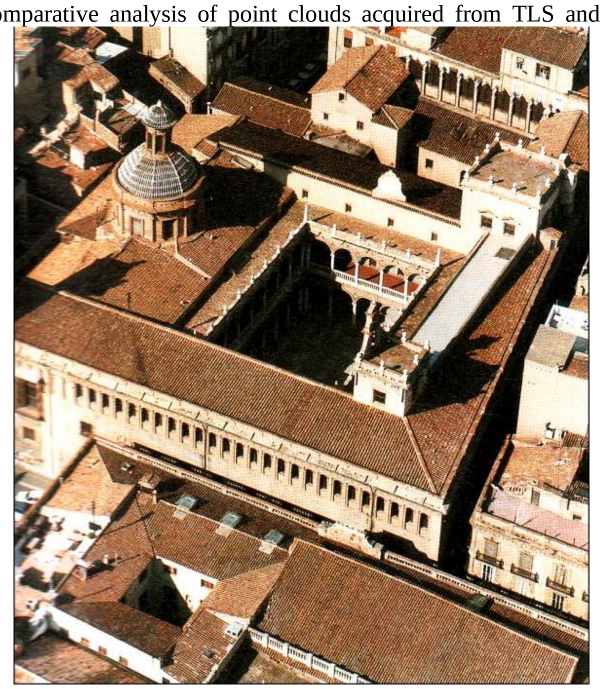
Using accurate and complete data acquisition techniques for HBIM development is crucial to ensure the digital model accurately represents the heritage building. Therefore, the comparative analysis of point clouds acquired from TLS and Matterport technology for HBIM development provides significant insights into improving the accuracy and efficiency of heritage documentation and preservation.



(a) A bird’s-eye view of the complex.

(b) The church.

(c) The façade.

(d) The renaissance cloister.

Figure 1. The Cloister of the Royal College of Corpus Christi Seminary, Valencia, Spain, was selected for case study of this research project. (authors’ photos)

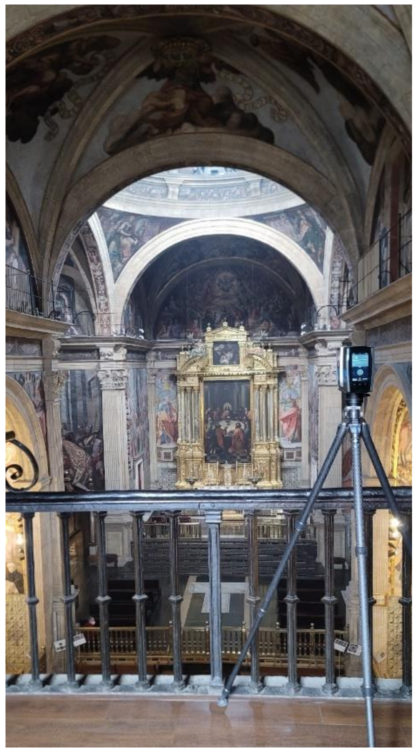
3.2 Data Acquisition Process

3.2.1 TLS Survey: To ensure comprehensive coverage of the Cloister of the Royal College of Corpus Christi Seminary, the TLS survey included the exterior facade, rooftop, cloister, and approximately 70% of the interior spaces, excluding the private quarters and classified rooms. To plan for the locations of the scans, floor plans were used to develop a comprehensive survey plan that would capture all necessary details. Two FARO Focus S-350 Laser Scanners were utilized for the TLS survey, with a total of 42 man-hours dedicated to the scanning process. A total of 341 scans were completed (including 38 exterior scans and 303 interior scans), with each interior scan taking between 4 to 5 minutes and each exterior scan taking 6.5 minutes. Field notes were maintained to track the scan locations and route for post-processing. Figure 2 includes a set of photos of the TLS survey.

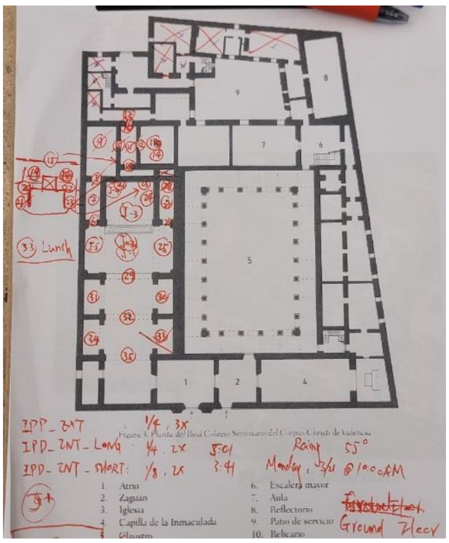
3.2.2 Matterport Scan: For data acquisition using Matterport technology, a Matterport Pro2 3D camera and an iPad mini tablet were utilized. Due to the range limit of this camera, the spacing among Matterport scans was much shorter than that of the TLS scans. To capture the necessary data, it took about 6 hours to complete the scanning process, resulting in 513 scans. The duration of each Matterport scan ranged from 20 seconds in the beginning to 30 seconds later in the process as more scans were added to the space. The majority of the scans covered the interior spaces of the Cloister of the Royal College of Corpus Christi Seminary, as the Matterport camera has very limited capacity for outdoor use. During the process, the Pro2 camera was moved manually from one location to another, capturing a series of images as it moved. Figure 3 illustrates the process of Matterport survey.

(a) A FARO Focus S-350 Laser Scanner scans the exterior façade.

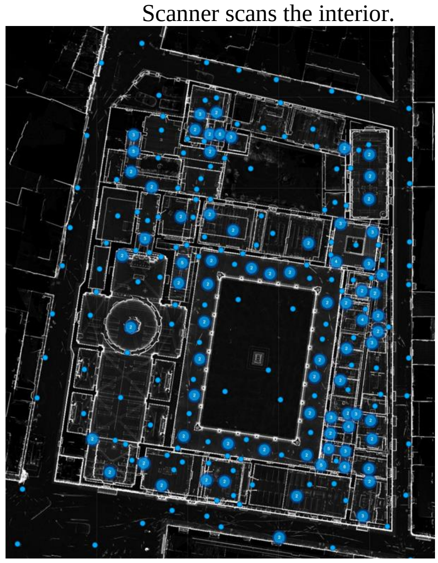
(b) A FARO Focus S-350 Laser Scanner scans the roof.



(c) A FARO Focus S-350 Laser Scanner scans the interior.



(d) Field notes were used to track the scan locations and record the scanner setting.



(e) An overview map shows all 341 scan locations.

Figure 2. TLS survey of the Cloister of the Royal College of Corpus Christi Seminary. (authors' photos)

3.3 Scan Data Processing

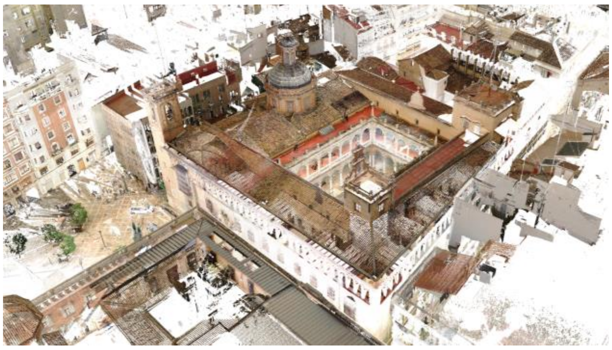
3.3.1 TLS Point Cloud: The 341 TLS scans obtained using the two FARO S-350 scanners were processed and registered using FARO SCENE software. The initial processing and colonizing of these scans were carried out after importing them into SCENE. Next, the registration process began, which involved grouping the scans into small clusters based on their scan locations. The small clusters were then merged to form nine larger clusters before the creation of a single point cloud. The resulting registered point cloud contained approximately 5.6 billion points and was exported as an Autodesk ReCap project (.RCP file) for further processing. The ReCap project was retrieved in Autodesk ReCap Pro for noise reduction and removal of points that were irrelevant to the historic building. Finally, the point cloud was unified in ReCap Pro and subsampled at 20mm to decrease its density. Figure 4 shows the TLS scan processing and the resulting point cloud.

(a) A Matterport Pro2 camera scans the interior.

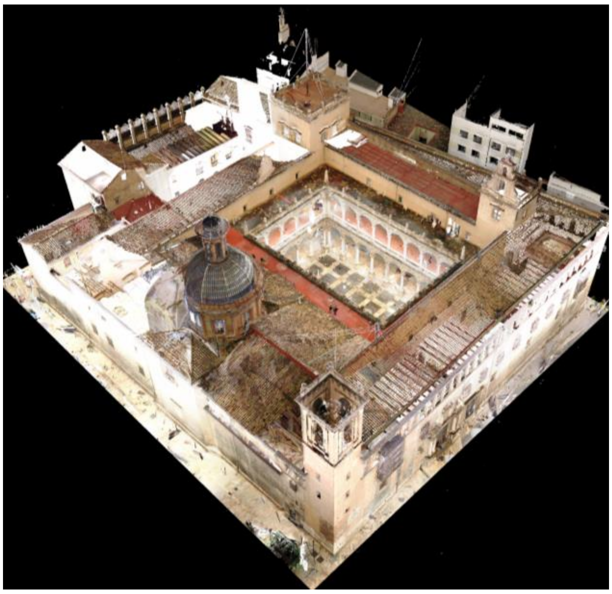
(b) A Matterport Pro2 camera scans the cloister.

Figure 3. Matterport survey was performed using a Pro2 3D camera. (authors' photos)

3.3.2 Matterport Data: The Matterport Pro2 camera utilizes a fisheye lens to capture a 360-degree view of each location. The captured images are then processed using Matterport cloud computing to generate an immersive virtual tour and a 3D point cloud. In this study, rather than using the immersive virtual tour that is produced by Matterport, the researchers focused on the point cloud data generated by the Matterport Pro2 camera. This point cloud was available to download as an E57 file as soon as the cloud processing was over. This file format contains a high-density point cloud for all scan locations in the Matterport space and includes point cloud, panoramic images, and metadata from each scan location. The E57 format is a compact, vendor-neutral point cloud format defined by the ASTM E2807 standard and is widely adopted by most 3D design applications (Matterport, 2022). By utilizing the E57 point cloud data from Matterport, the researchers were able to create a unified point cloud with point spacing of 20mm in ReCap Pro. Figure 5 shows the resulting Matterport point cloud. It appears that this point cloud lacks information of the roof and exterior facade of the building. This is due to the range limit of the Matterport technology, which can only capture a short distance, up to 15 ft (or 4.6 m), from each scan location. However, the point cloud does provide highly detailed information for the interior spaces of the building, which is the focus of this study.



(a) The "raw" registered TLS point cloud shown in FARO SCENE.



(b) The "cleaned" and unified TLS point cloud shown in Autodesk ReCap Pro.

Figure 4. TLS point cloud processing.

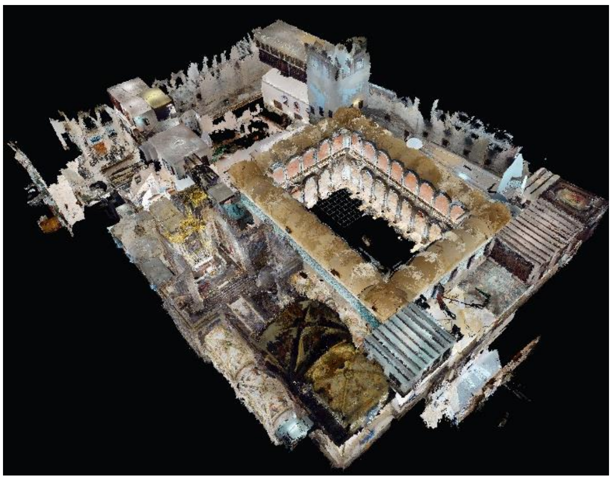


Figure 5. Matterport point cloud.

3.4 Point Cloud Comparison Techniques

For the comparative analysis of the TLS and Matterport point clouds in this study, CloudCompare software was utilized. CloudCompare is a widely used free and open-source tool for

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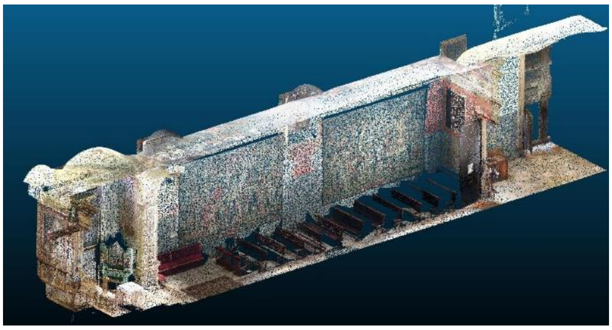
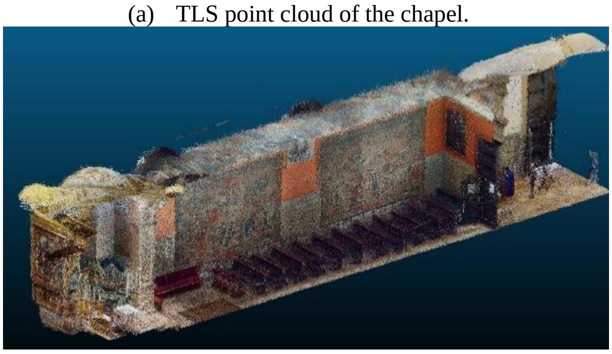
processing and comparing 3D point clouds. Due to the large size of each point cloud dataset, only one section of the interior facade of a chapel on the ground floor was selected for the comparative analysis. The section was chosen for its complex geometry and intricate decorative elements, providing a suitable test area for the accuracy of the TLS and Matterport cloud datasets. To isolate the region of interest, a point cloud was extracted from the subsampled TLS point cloud, resulting from 4 TLS scans completed in approximately 25 minutes of scanning time, and from the Matterport point cloud, resulting from 18 scans completed in around 10 minutes, separately into .e57 file format (as illustrated in Figure 6). Subsequently, both point clouds were loaded into CloudCompare and aligned using the iterative closest point (ICP) algorithm, minimizing the difference between the two point clouds. Finally, the distance between the corresponding points in the two point clouds was calculated to evaluate the accuracy of the Matterport point cloud compared to the TLS point cloud. Visual comparison of the two point cloud datasets was also performed.



(a) TLS point cloud of the chapel.



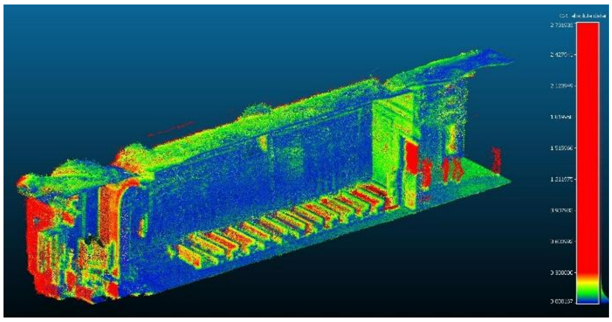
(b) Matterport point cloud of the same chapel.

Figure 6. The two sections of point cloud used for comparison analysis in this study.

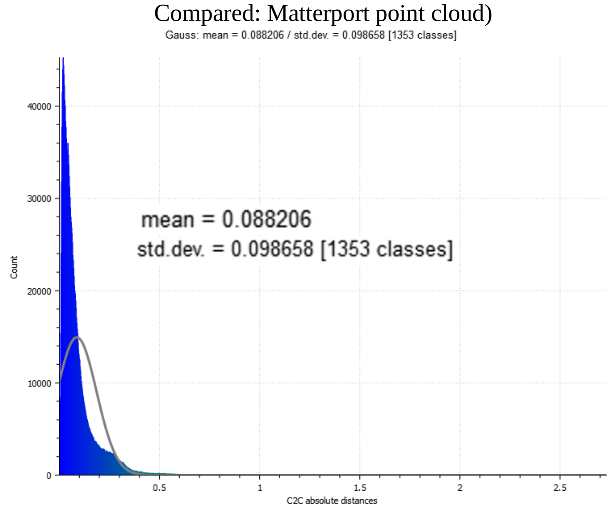
4. RESULTS AND ANALYSIS

4.1 Quantitative Comparison

To assess the quality and accuracy of the Matterport point clouds and the TLS point cloud, several indicators were used, including the mean point-to-point distance, the standard deviation of the point-to-point distance, the percentage of points with a distance greater than 5 mm, and the octree level. The octree level was set to 8, which improved the processing time while still providing a high level of detail. The results of the analysis, as illustrated in Figure 7, show that the mean distance between the corresponding points in the two point clouds is between 0.05 – 0.08 m. The standard deviation is between 0.086 – 0.098. These values indicate that the Matterport point cloud is relatively accurate in comparison to the TLS point cloud.



(a) Comparison test result. (Reference: TLS point cloud; Compared: Matterport point cloud)



(b) Mean distance and standard deviation of the corresponding points in the two point clouds.

Figure 7. Results of quantitative analysis in CloudCompare.

Additionally, less than one percent of the points had a distance greater than 5 mm, which further indicates the high level of accuracy of the Matterport point cloud. The results of the analysis suggest that Matterport technology is a viable alternative to TLS for cultural heritage documentation and preservation.

4.2 Visual Comparison

In addition to the quantitative analysis, a visual comparison of the two point clouds was also carried out. This visual comparison revealed several differences in the level of detail captured by each technique. The TLS point cloud appeared to have captured more details of the decorative elements and complex geometry of the chapel's interior facade, while the Matterport point cloud appeared to have captured more of the missing points between the benches in the room (as shown in Figure 7a) due to its higher number of scans. However, the Matterport point cloud exhibited more noise and artifacts in the areas where the scans overlap, while the TLS point cloud appeared to have more uniform density and fewer artifacts. These observations are supported by the quantitative analysis, which shows that the Matterport point cloud has a higher number of points than the TLS point cloud but exhibited more noise and outliers, as evidenced by the higher standard deviation values. The TLS point cloud has fewer points but exhibited a more uniform density, resulting in a more precise and accurate representation of the chapel's interior facade.

In summary, the Matterport point cloud data was found to be of a slightly lower quality and accuracy compared to the TLS data, but it still proved sufficient for developing some low-tolerance geometry in the HBIM model, including basic shapes such as walls, floors, and ceilings, as well as simple geometric features such as columns and arches. The Matterport point cloud data can be used to supplement TLS scans, especially in cases where the Matterport data provides coverage of areas that were missed during the TLS survey due to the range limitation.

5. CONCLUSION

While using 3D point cloud data to develop HBIM models, resolution (or accuracy) and quality are the two most important parameters for point cloud datasets (Palcak et al., 2022). The aim of this research was present a process to document the heritage structure using multiple RC techniques and conduct a comparative analysis of point clouds acquired for HBIM development from a TLS survey and Matterport technology. The study utilized the Cloister of the Royal College of Corpus Christi Seminary, an important cultural heritage site in Valencia, Spain, as a case study. The resulting point clouds from TLS survey and Matterport scans were compared quantitively in CloudCompare software and visually to assess their accuracy and quality. The Matterport point cloud data was found to be of a slightly lower quality and accuracy compared to the TLS data. The visual comparison revealed that the Matterport point cloud captured some details missed by the TLS point cloud due to its higher number of scans, but exhibited more noise and artifacts in areas where the scans overlap. Despite these limitations, the Matterport point cloud data proved sufficient for developing some low-tolerance geometry in the HBIM model.

The results of the study showed that the Matterport point cloud data can supplement TLS scans, especially in areas missed during the TLS survey due to range limitations. The benefits of using Matterport technology for cultural heritage documentation and preservation include its accessibility, affordability, and ease of use. Non-experts can operate the technology with minimal equipment, making it a feasible option for heritage sites with limited resources. Furthermore, Matterport technology captures high-quality visual data, including color and texture, providing a detailed representation of the heritage site. Another advantage of Matterport technology is its cloud-based data processing, which eliminates the need for user intervention, although it may lack the flexibility and customization of traditional surveying methods. Therefore, Matterport technology can be a valuable contribution to cultural heritage documentation and preservation, particularly for sites with limited resources or requiring a quick and efficient surveying process. Future research could explore the use of other 3D scanning technologies and their comparison to TLS and Matterport for heritage documentation and preservation.

However, it is also important to note the limitations of this study. The study only compared the point clouds of a small section of the building, and the comparison was limited to a quantitative and visual assessment. Future research could expand the comparative analysis to the entirety of the building, using additional techniques for accuracy assessment. Additionally, further research could explore the potential of integrating the two technologies to develop a more comprehensive and accurate HBIM model.

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