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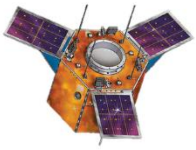

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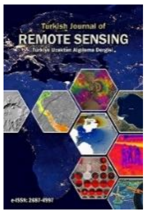

Production of WebGL Based Digital Documentation of Ponte Molino Gate From Point Cloud

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ABSTRACT

In recent years, the rapid presentation and sharing of data obtained through photogrammetric techniques have gained significant importance in digital documentation projects. This study focuses on the digital documentation of the historically significant Ponte Molino Gate in Padova, Italy. Dating back to 40–30 BC, this structure was scanned using a terrestrial laser scanner (TLS), resulting in the creation of a comprehensive point cloud. The obtained data was visualized using Potree, a WebGL-based software, and prepared for online presentation. The study highlights Potree's capabilities in processing and visualizing point cloud data within a hierarchical structure, as well as its advantages in facilitating the virtual sharing and interactive exploration of cultural heritage assets. This approach demonstrates broad application potential in fields such as GIS, terrain modeling, and urban planning. The results indicate that Potree effectively reduces point cloud data size by 80% while retaining its hierarchical structure, thereby enabling efficient visualization and presentation. The findings also show that the data was reduced to a minimal file size for online accessibility, improving the preservation and accessibility of cultural heritage by 60%.

Ponte Molino Kapısının Nokta Bulutundan WebGL Tabanlı Dijital Dokümantasyonunun Üretimi

Anahtar Kelimeler:
Dokümantasyon
Kültürel Miras
Octree
WebGL

ÖZ

Son yıllarda fotogrametrik tekniklerle elde edilen verilerin dijital dokümantasyon projelerinde hızlı bir şekilde sunulması ve paylaşılması büyük önem kazanmıştır. Bu çalışmada, İtalya'nın Padova şehrindeki tarihi öneme sahip Ponte Molino Kapısı'nın dijital dokümantasyonu yapılmıştır. MÖ 40-30 yıllarına tarihlenen bu yapı, bir yersel lazer tarayıcı (TLS) ile taranmış ve kapsamlı bir nokta bulutu oluşturulmuştur. Elde edilen veriler, Potree yazılımı kullanılarak WebGL tabanlı bir ortamda görselleştirilmiş ve çevrimiçi sunum için uygun hale getirilmiştir. Çalışma, Potree'nin nokta bulutu verilerini hiyerarşik bir yapıda işleme ve görselleştirme yeteneklerini, ayrıca kültürel miras varlıklarının sanal ortamda paylaşılması ve etkileşimli olarak incelenmesi için sunduğu avantajları ortaya koymaktadır. Bu yaklaşım, GIS, arazi modelleme ve kentsel planlama gibi alanlarda geniş bir uygulama potansiyeline sahiptir. Çalışmanın sonuçları, Potree'nin nokta bulutu verilerini %80 oranında küçülterek hiyerarşik bir yapıda işleme ve görselleştirme yeteneklerini, ayrıca kültürel miras varlıklarının sanal ortamda paylaşılması ve etkileşimli olarak incelenmesi için sunduğu avantajları ortaya koymaktadır. Sonuçlar, elde edilen verilerin düşük dosya boyutuna indirgenerek çevrimiçi erişilebilir hale getirildiğini ve bu sürecin kültürel mirasın korunması ile erişilebilirliğini %60 daha verimli kıldığını göstermektedir.

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1. INTRODUCTION

In recent years, the easy, practical, rapid presentation and sharing of data obtained through photogrammetric methods have become the subject of many research studies. Data presentation and sharing are crucial in digital twins, historical artifacts documentation and smart city projects (Amirebrahimi, Rajabifard, & Sciences, 2012; de Kleijn et al., 2024; Döş & Yiğit, 2023; Jung et al., 2024; La Guardia & Koeva, 2023; Makineci & Erdal, 2021; Nguyen, Nguyen, Vo-Lam, Nguyen, & Tran, 2016). In this context, web-based applications developed to visualize and share data effectively have enabled such data to be easily, practically, and rapidly presented and shared. Additionally, with the contributions of the web graphics library (WebGL), these applications have the potential to simplify the understanding of complex datasets, enhance project management, and improve overall efficiency (Drap, Grussenmeyer, Gaillard, Curtinot, & Seinturier, 2004). WebGL allows for the rapid processing of data that cannot fit into memory directly within a browser, enabling software in this field to provide impressive and interactive visualizations (Drap et al., 2004; Klepárník & Sedlácek, 2021).

The presentation of documented cultural structures and artifacts to users in quick and practical ways is as important as the documentation process itself. In a sample study, a historical cultural structure was documented using photogrammetric techniques. Following the cultural documentation process, a WebGL-based virtual tour platform was created to share the obtained data and present all architectural details comprehensively. This platform was made available to users and shared for use in other studies (Fascia, Barbieri, Gaspari, Ioli, & Pinto, 2024). There are many studies similar to this one. The common factor among these studies is their use of self-developed WebGL-based platforms and applications (Klepárník & Sedlácek, 2021; Szujó, Biber, Gál, & Szabó, 2023). Another sample study reviewed the creation of a 3D model, point cloud data, and 360° imagery of a cultural heritage artefact using photogrammetric techniques. The data obtained was successfully shared online using the Potree application. The study highlighted that the application effectively facilitates the online sharing of 3D models and point cloud data. Additionally, it emphasized that this WebGL-based visualization is a fast and practical WebGL-based application, particularly noting the benefits of adding images, annotations, and details to the model (Apollonio, Fantini, Garagnani, & Gaiani, 2021). Also, in various studies related to Geographic Information Systems (GIS), cultural heritage documentation, virtual tours, and similar objectives, This application has been frequently employed for sharing obtained data online without the need to develop a WebGL platform (Nguyen et al., 2016; Sánchez-Aparicio et al., 2020). Potree, a web-based visualization tool built on WebGL technology and completed in 2016, enables the easy visualization and presentation of large-scale point clouds and 3D model datasets within a browser. The application offers both online use in WebGL format and offline use through a desktop version. Potree can be quickly utilized by downloading its open-source library and completing the installation steps. This software is user-friendly, allowing even those with limited experience in 3D navigation to use it effectively. It simplifies the process further with dynamic annotations and predefined animations applied to the datasets. Additionally, a distinguishing feature of the software, compared to other WebGL software, is the ease of use of its technical tools, such as measurement and cross-section capabilities (Gaspari et al., 2023; Jung et al., 2024; Martinez-Rubi et al., 2015; Markus Schütz, 2015).

The primary operational principle of the application is its ability to handle extensive memory-intensive data. This capability relies on Potree's use of a modifiable nested octree (MNO) structure. The modifiability of this structure refers to the dynamic use and scalability of the data organization. One of the main reasons application employs the MNO structure is to progressively organize the dataset, thereby providing users with a more effective way to explore and examine large-scale point clouds (Markus Schütz, 2015).

The unique features offered by the Potree application enable its broad applicability across various fields, such as GIS, terrain modeling, urban planning, and archaeology. The application has become a significant tool for experts and researchers working with large-scale datasets (Markus Schütz, 2015). Potree's areas of application support more effective analysis and sharing of data produced through photogrammetric techniques, thereby enhancing the potential of this technology (Carey, Romero, Laefer, & Sciences, 2021; de Kleijn et al., 2024; Fascia et al., 2024),

In contemporary times, the preservation and accurate documentation of historical, artistic, and architectural cultural artifacts are directly dependent on digital documentation processes (Fascia et al., 2024). Additionally, after the completion of the digital documentation process for cultural artifacts, the creation of digital archives, their accessibility to various users, and the ongoing maintenance of these archives are of great importance (Apollonio et al., 2021; Fascia et al., 2024; Quintilla-Castán, Martínez-Aranda, & Agustín-Hernández, 2022). For the purpose of ensuring that information about digitally documented cultural artifacts is quickly and easily accessible and to serve as a resource for scholars, architects, and restoration experts, the digital documentation of cultural artifacts is shared using software and platforms based on WebGL technology (Apollonio et al., 2021; Dall'Asta, Leoni, Meschini, Petrucci, & Zona, 2019; Masciotta et al., 2021; Sánchez-Aparicio et al., 2020). This situation facilitates the management and maintenance of cultural artifacts and additionally provides significant support in the planning and monitoring of research activities related to cultural heritage (Fascia et al., 2024).

Sharing digitally documented cultural artifacts on software and platforms built on WebGL technology offers numerous advantages. However, the problems and challenges encountered during this process are essential areas that require investigation (Apollonio et al., 2021; Boutsi, Ioannidis, & Soile, 2019; Szujó et al., 2023). The challenges faced in presenting and sharing large-scale data, the complex stages involved, and the encountered errors can adversely affect the process. This study aims to contribute to and share the digitally documented Ponte Molino Gate, located in Padova, Italy, using Potree. The primary reason for selecting Ponte Molino Gate for this study is its historical significance, dating back to 40-30 BC, making it one of the significant historical artifacts from the Roman period that still exist today. This gate, integrated with a bridge, is one of the two gates from the Roman era that is still actively used today, adding to its value. In line with this aim, the study seeks to examine in detail the working principles and internal dynamics of the Potree application, identify key considerations in the stages of presenting and sharing digital documentation using Potree, address potential errors, and assess the advantages and disadvantages.

2. MATERIAL AND METHOD

Ponte Molino Gate stands as one of the most significant medieval historical monuments in Padova (see Figure 1). Currently in active use, the gate and the adjacent bridge derive their name from the 34 watermills that floated on the river in the 1300s. Although these watermills were removed between 1883 and 1884, the historical structure of the Ponte Molino Gate and Bridge has been preserved. This gate, standing 26 meters high, is estimated to have been constructed around 40-30 BC. Despite being damaged numerous times, it has been rebuilt using original materials. Ponte Molino Gate and Bridge are one of the two remaining bridges from the Roman era that are still in use today. Aside from providing access to one of the city's main roads, one of the primary purposes for constructing this gate was for defence, evidenced by its oval arch with a strong tower. The historical significance and narrative of the gate extend beyond this. According to an inscription by Carla Leoni (1812-1874), a figure known for her writings on Padova's walls, it is said that Galileo observed the skies and saw Jupiter's four moons from the tower of Ponte Molino Gate. To ensure the preservation and transmission of this important cultural heritage to future generations, producing a digital twin and documenting the gate is essential. In this context, Ponte Molino Gate was scanned using a terrestrial laser scanner (TLS). Following the scanning process, a point cloud of the historic gate was obtained through data processing. Upon examining the point data of the historic gate, it was determined that the architectural details of the gate were clearly understandable and sufficient for the digital documentation process. To present and share the obtained 3D point cloud, the data of Ponte Molino Gate was transferred to software.

Figure 1. Ponte Molino Gate

2.1. Web-Based Visualization Tool

Together with technological advancements in 3D web-based visualization and editing applications, the process of digital documenting and sharing of important structures has rapidly become widespread (Amirebrahimi et al., 2012; Nguyen et al., 2016). Web-based visualizations facilitate the increase and spread of virtual environments such as e-museums, virtual education platforms, and simulation studies, and the use of 3D models contributes to these applications (Makineci & Erdal, 2021). Additionally, virtual tour applications and panoramic videos also aid in enriching virtual environments through visualization technologies. This allows users to visit various locations, experience realistic simulations in a virtual setting, and interactively explore content (Boutsi et al., 2019; Schultz, Kerski, & Patterson, 2008).

Potree is a JavaScript 3D web viewer that enables the rendering of large point clouds and provides features such as interaction with 3D objects, predefined views, measurements, and cross-sections. This viewer allows users to share and visualize point cloud data in various formats, including popular 3D file formats such as LAS, LAZ, PTX, and PLY. The core structure of the viewer consists of measurement tools, object views, filter tools, and controls. Additionally, georeferenced annotations are one of Potree's key features, enabling the definition of the position and title of a label within the 3D scene (Gaspari et al., 2023; Markus Schütz, 2015). Another significant feature of the application is the ability to select different point attributes for visualization. This feature provides a considerable advantage in the rapid web-based visualization and presentation of point clouds or 3D models within a single application for various studies and purposes. Additionally, it allows for the integration of spatially distributed technical data into the 3D point cloud, making it useful for conservation and management projects involving digital inventories (Gobbetti & Marton, 2004; Markus Schütz, 2015).

In this study, the point cloud obtained from the TLS of the Ponte Molino Gate was uploaded to the web-based visualization program Potree (Figure 2). Also, Figure 3 shows the visualization of the Ponte Molino Gate using different point attributes on the application.

Figure 2. Potree user interface

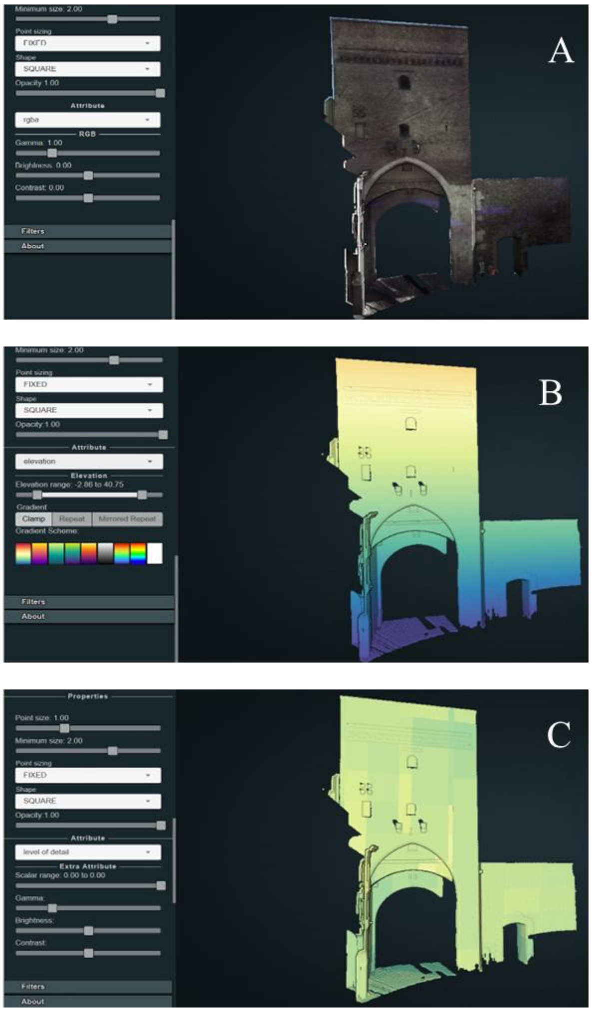

Figure 3. Point attribute coloring (A: RGB, B: Elevation C: Level of detail)

2.2. Method

The primary principle of web-based visualization tools hinges on their ability to handle large datasets that do not fit into memory. Potree achieves this capability through its hierarchical octree structure. Potree's octree structure is based on a modifiable hierarchical octree, although it does not provide the functionality to modify the point cloud structure. This section will discuss the operational principle of the visualization tool. Before examining the Potree Octree Structure, it is necessary to review the Modifiable Nested Octree, which forms the foundation of this structure.

2.2.1. Modifiable Nested Octree (MNO)

The Modifiable Nested Octree (MNO) structure is a hierarchical data structure that organizes a point cloud by subdividing it into smaller, structured subsamples. At the upper levels of the octree, nodes represent larger spatial volumes with lower point densities, like dividing a large room into broad zones. As the hierarchy progresses to deeper levels, the spatial volume of each node decreases and the points within these nodes become more concentrated, similar to further dividing each zone into smaller, detailed sections (Markus Schütz, Ohrhallinger, & Wimmer, 2020).

The MNO operates using a nested 128-cell three-dimensional grid to generate these subsamples. Initially, all points are assigned to the root node and each point is allocated to the point first grid cell it occupies. For example, imagine placing marbles into a grid where each cell represents a small compartment; each marble is assigned to the firstcompartment it touches. If a cell already conntains points and the node's total point count is below a predefined thereshold, new points are added to this cell. Instead of creating a new grid for every filled cell, a filled array is used to store point data efficiently. This prevents the unnecessary creation of sub-nodesi thereby reducing memeory usage and speeding up the processing (Scheiblauer, Wimmer, & Graphics, 2011).

2.2.2. Potree's Octree Structure

Potree creates a specialized data structure to efficiently handle large amounts of 3D point clouds. The core data structure of Potree is the "Octree." This octree structure hierarchically organizes three-dimensional space (Guarnieri, Vettore, & Pontin, 2005). This structure creates a bounding cell at the general boundaries of large 3D point clouds. This cell must encompass the entire point cloud. The minimum and maximum coordinate values along the x, y, and z axes are determined and fixed for this bounding cell. The bounding cell is then divided into eight equal subcells, enabling fast access and visualization. This hierarchical division continues until the data is partitioned into smaller cells (Markus Schütz, 2015). As a result, each point in the point cloud is placed into a cell within the octree structure, with each cell containing its assigned bounding cell and a list of the points it contains (Figure 4). Thus, the point cloud is represented in a hierarchical structure (M. Schütz & Wimmer, 2015).

The cells constitute the parts, with each part representing a node. At each level, as the size of a node decreases, the point density increases (La Guardia & Koeva, 2023; Rusinkiewicz & Levoy, 2000). Each node can be processed independently, providing a suitable structure for parallel computations. The ability to independently process cells and form parts offers a performance advantage in visualizing and presenting large point clouds (Rusinkiewicz & Levoy, 2000; Markus Schütz, 2015; Wand et al., 2007).

Figure 5 illustrates how the Potree Octree structure is applied to the point cloud. This figure visually explains how the point cloud is subdivided into the octree structure and how each cell is organized.

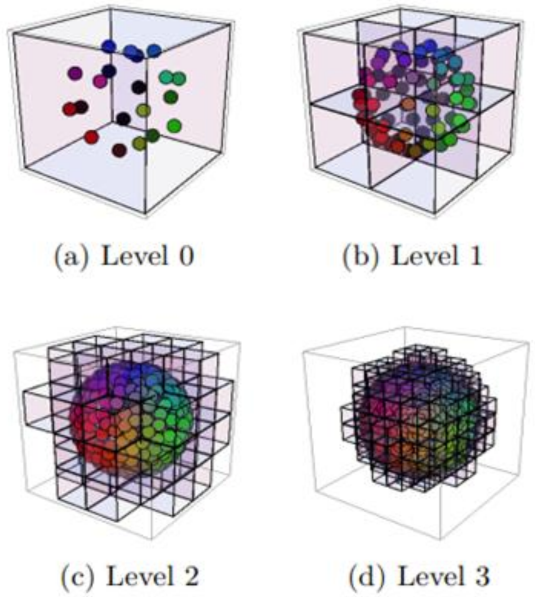

Figure 4. Placing each point of the point cloud into the cell of the octree structure (Markus Schütz, 2015)

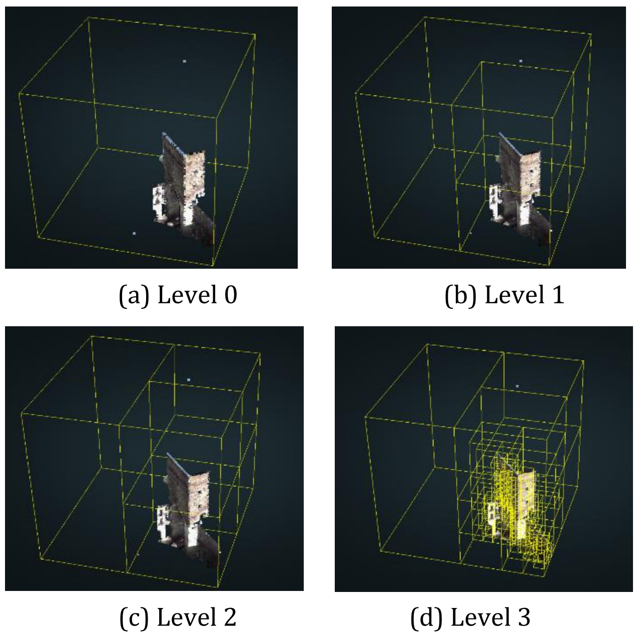

Figure 5. Application of Potree Octree Structure to Point Cloud

If a node contains a large number of points, the Potree Octree Structure divides the node into smaller parts. If the number of points within the node is small, the node is not further subdivided. Larger nodes represent general boundaries and contain more minor, more specific nodes. This arrangement provides a level of detail (LOD) mechanism. The LOD dynamically adjusts the level of detail by adding or removing nodes based on the viewer's distance to the area being visualized. A more general view is presented as the viewer zooms out while zooming in reveals more details (Scheiblauer, 2014). Thus, Potree optimizes performance and provides a faster experience for users when processing and visualizing large point clouds. Rapid rendering is significant during the process of interactively navigating through point data (Wimmer & Scheiblauer, 2006).

3. APPLICATION AND DISCUSSION

3.1. Application

The study presents the WebGL-based digital documentation of the Ponte Molino Gate in two stages. In the first stage, the point cloud data was processed using a Potree Converter and converted into the octree structure of the Potree application. In the second stage, the processed data was transferred to a free web hosting platform, making it ready for online presentation (Figure 6).

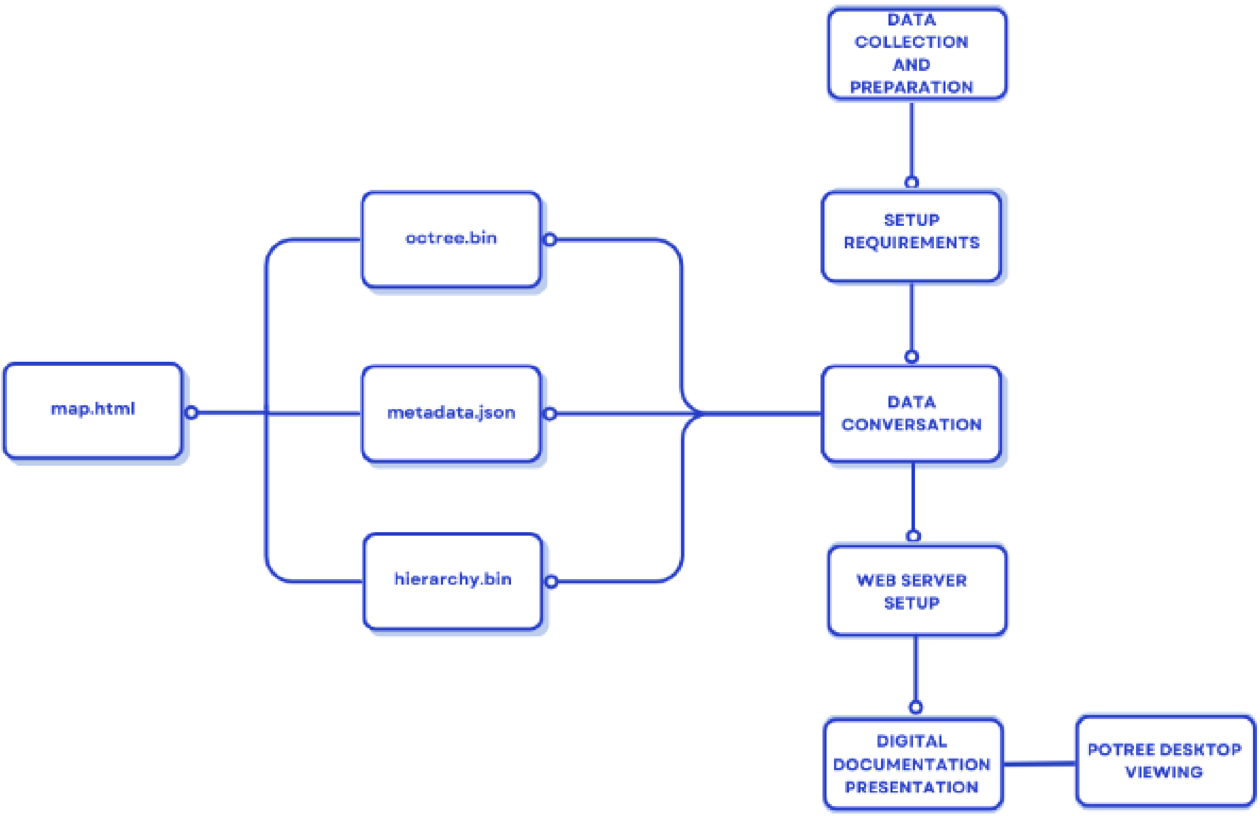

Figure 6. Workflow chart

3.1.1. Conversion of Data into Octree Structure

The Potree application's working principle requires converting the original point cloud into an octree structure, within which the data are hierarchically organized, enabling quick access and efficient processing.

The transformation of the point cloud into an octree structure is accomplished using the Potree Converter. This tool processes, organizes and configures the data to be compatible with the data structures used by Potree, employing various parameters for optimal performance. As an integral part of the workflow, correct configuration and parameter choice in the Potree Converter are crucial for effective visualization of data within the Potree application. The conversion process using the Converter can be conducted in two ways.

The first conversion is performed using the desktop version of Potree, which includes the Converter. Once the installation is complete, the point cloud data is processed using this tool, which automatically generates the files octree.bin, metadata.json and hierarchy.bin.

In the second conversion method, the transformation process is conducted using the command line. For this process, it is sufficient to install Potree Converter and run it via the command line. The point cloud data is processed using the following command (1), which generates the octree.bin, metadata.json, and hierarchy.bin files:

PotreeConverter /path-to-pointcloud-file/pointcloud.las -o /path-to-output-directory

In both methods, after the conversion process, an HTML file is created using the command line to facilitate the presentation of the data. This can be done with the following command (2):

PotreeConverter.exe/path-to-pointcloud-file/ pointcloud.laz/pointcloud.las -o /path-to-output-directory --generate-page YourPageName

The resulting octree.bin, metadata.json, hierarchy.bin files, along with the generated HTML file, are then ready for online presentation. This setup ensures that the converted point cloud data can be effectively visualized and shared through the web using Potree.

3.1.2. Online Presentation of Data

One of the key features of the Potree application is its ability to present data online. Since Potree is web-based, the data is accessible through a web browser. Users can easily access and examine high-resolution point clouds and 3D models. The online presentation of data facilitates project sharing and collaboration. After the data is converted into an octree structure, it is transferred to a platform offering free web hosting services to ensure easy sharing with other users, allowing the model to be presented online.

Upon completing the processing steps, the Ponte Molino Gate was successfully transferred to the Potree application and shared online on the Potree platform. The cultural documentation data for Ponte Molino Gate can be accessed at http://potree.altervista.org/test/_PortaM.html (see Figure 7).

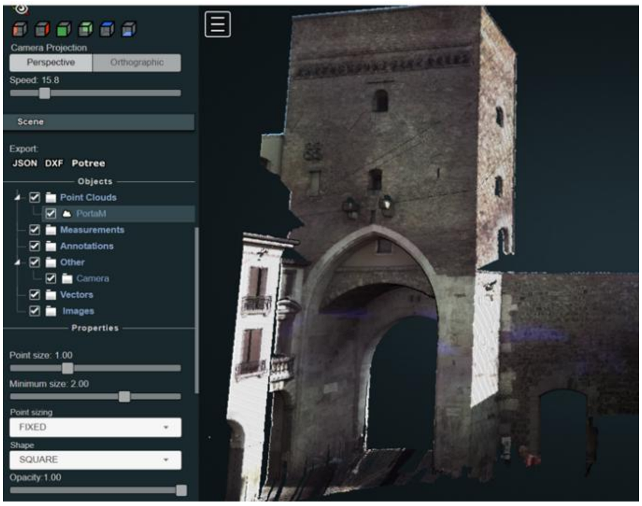

Figure 7. Online presentation of the Ponte Molino Gate

3.2. Discussion

The Potree application and platform is a significant web-based visualization tool that allows users to easily visualize and present large-scale datasets in a browser. It is noted for providing a robust and user-friendly platform for the effective presentation of 3D data. The features offered by Potree are highlighted for their broad applicability across various fields, such as GIS, terrain modelling, urban planning, and archaeology (Carey et al., 2021; de Kleijn et al., 2024; Nguyen et al., 2016; Szujó et al., 2023). Within the scope of this study, the 3D model of the Ponte Molino Gate was shared online on the Potree platform. Considering the data used in this study, it is evident that its application can be expanded to cover a broader area. In similar studies, cultural heritage data has been evaluated on a wide scale, and it has been emphasized that one of the significant advantages provided by Potree is the inclusion of information and visuals related to cultural heritage. Additionally, in similar studies, the Potree platform has been integrated into a web browser specifically designed for cultural heritage, and the data has been presented to users online through this website (Apollonio et al., 2021; Boutsi et al., 2019; de Kleijn et al., 2024; Fascia et al., 2024). In future stages, it is anticipated that, as with other studies, presenting the Ponte Molino Gate on a dedicated website on a large scale will play a crucial role in reaching a wider audience for the cultural documentation of the Ponte Molino Gate.

The file sizes of TLS data present numerous challenges in terms of data presentation and sharing. One of the primary advantages of visualizing point clouds in a web browser is that users can share datasets without the need to install third-party applications or transfer large amounts of data. Laser scanning data obtained through WebGL-based platforms have been available online to users. However, specific information about file sizes and data transfer rates has not been disclosed. Potree focuses on large point clouds and provides users with tools for examining, analyzing, and verifying raw point cloud data using various measurement tools. Furthermore, the size of the LAS file before conversion was 19,713 KB. At the same time, the metadata.json file size after conversion decreased to 4 KB. Potree offers advantages over other WebGL-based platforms in terms of data size and data processing speed (Fascia et al., 2024; Markus Schütz et al., 2020).

4. CONCLUSION

The digital documentation of the Ponte Molino Gate using Potree serves as an effective approach to preserving and sharing cultural heritage. Potree's hierarchical octree structure efficiently processes and visualizes large point cloud datasets, making it a robust tool for fields that require detailed 3D modeling. Its ability to render point clouds in real time reduces loading times, significantly enhancing the user experience when working with extensive datasets. Additionally, its highly accurate measurement capabilities provide valuable support for precise analyses. However, its reliance on the graphics processing unit (GPU) during rendering poses a limitation for users with older hardware. Moreover, its visualization capabilities are restricted to point clouds, which may not meet the needs of projects that demand more versatile visual solutions.

This study highlights the significance of Potree's WebGL-based structure in improving the accessibility and usability of complex datasets. WebGL technology plays a crucial role in this process by operating directly through web browsers without requiring external plugins or software, enabling users to access and interact with the application effortlessly. Its ability to render graphics in real time provides immediate feedback, resulting in a smoother and more responsive experience. Additionally, WebGL's compatibility with various operating systems and devices allows Potree to cater to a broad audience. The web-based nature of Potree also facilitates easy sharing and distribution, extending the reach and accessibility of the project. These features present an innovative method for quickly and easily transferring many cultural heritage sites into the digital realm. As a WebGL-based point cloud viewer, Potree ensures that large datasets can be easily shared and accessed over the internet, facilitating collaboration among researchers and professionals.

Moreover, during the conversion process, Potree significantly reduces the size of datasets. For instance, the size of the original LAS file, which was 19,713 KB, was reduced to just 4 KB in the resulting metadata.json format. This reduction not only facilitates efficient storage but also enables faster data sharing and processing.

Potree's real-time rendering capabilities also allow for the rapid and efficient visualization of large point cloud datasets, which is particularly beneficial in fields such as architecture, engineering, and construction where quick and accurate project evaluations are crucial. In the realm of education and research, Potree offers students and researchers a deeper, hands-on learning experience by allowing them to analyze and visualize complex datasets. Moreover, the high-precision measurement and analysis features of Potree provide valuable support for data scientists and engineers in performing detailed and reliable analyses, contributing to more efficient project management.

Looking ahead, Potree's ongoing development as an open-source project holds the potential for further technological advancements and feature enhancements. This positions Potree to better meet user needs and adapt to new technological trends in the future. Future research will focus on addressing challenges in data presentation and sharing, further optimizing WebGL's integration within Potree to improve performance, and expanding visualization capabilities beyond point clouds to meet the evolving demands of digital documentation projects.

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Author contributions

B. Güvercin: Methodology, Software, Formal analysis, Writing - Original Draft and Visualization.

K. Erdal: Validation, Investigation and Writing - Original Draft.

H.B. Makineci: Conceptualization, Writing - Original Draft, Writing - Review & Editing and Supervision.

A. Guarnieri: Resources, Data Curation, Writing - Original Draft, and Project administration

Conflicts of Interest

There is no conflict of interest between the authors.

Research and publication ethics statement

In the study, the author/s declare that there is no violation of research and publication ethics and that the study does not require ethics committee approval.

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