3D SURVEY POINT CLOUD DATA AS DIRECT RENDERING ASSETS FOR VISUALISING COMPLEX HERITAGE IN VIRTUAL APPLICATIONS

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ABSTRACT:

Digital technology provides methods to record and preserve cultural heritage, support conservation and restoration efforts, and share our collective past with a worldwide audience. Between 2011 and 2017, the 3D Survey Group from Politecnico di Milano operated an annual workshop in the medieval village of Ghesc in which photogrammetry and laser-scanner surveys were carried out. The point cloud data acquired in these activities has become "time slices" documenting different stages of the preservation interventions in Ghesc and the evolution of advanced survey techniques. The main objective of this research is to streamline the workflow of delivering immersive and interactive experiences for complex heritage by directly utilising the 3D survey point cloud data, whether derived from a photogrammetric survey, static laser scanner, or mobile mapping.
A point cloud-based multiplatform application is designed and delivered with versatile functions. It runs on PC and VR devices to provide virtual access to the village and narrate its revitalisation story. Additionally, it operates on mobile devices with an AR feature that brings vibrancy to the on-site experience. This application integrates high-fidelity point cloud models, detailed information on vernacular architecture in the Ossola Valley, and information on the preservation project with gamified learning experiences. The unconventional approach of using points as rendering primitives in virtual applications offers a practical solution for visualising complex heritage, enabling an efficient transition from the data collection stage to the data sharing stage without the need for 3D reconstruction and intricate BIM modelling.

1. INTRODUCTION

This proposal presents the results of multidisciplinary research in which raw data from 3D surveys is directly used to deliver virtual experiences for complex cultural heritage. The case study is Ghesc, a medieval stone village. Over the past decade, this hidden gem has begun to undergo restoration. This research seeks to utilise the survey data acquired in Ghesc over the years to determine the most efficient workflow for representing heritage in virtual applications for education and appreciation uses. As an outcome, a point cloud-based multiplatform application is designed and delivered to provide interactive and immersive experiences for village discovery.

The direct integration of 3D point cloud data into the digital representation and fruition process forms a central concern of this research. Traditionally, mesh modelling has been the prominent method to visualise cultural heritage in a virtual environment. Mesh is undeniably useful because it is easier to handle in VR/AR applications, and the texture can provide excellent detail even with a model with few polygons. Yet, optimising and aggregating these models is usually time-consuming and highly specialised. In comparison, the simple elaboration of raw data from 3D scanners into processed point cloud data eliminates the complex 3D reconstruction processes associated with mesh or CAD modelling. Rather than merely serving as a stepping-stone to creating 3D models, point cloud data has numerous advantageous characteristics for faithfully visualising cultural assets. For instance, point clouds can be updated with new data straightforwardly without the need to remodel the entire entity.

Many previous works have been dedicated to the optimisation of reconstructive modelling and the scan-to-BIM-to-XR method for preserving and sharing cultural heritage. Contrastingly, point clouds - the first product of a 3D survey - are rarely put into direct use to represent cultural heritage for a wider audience but have instead to be treated and transformed into other formats. Recent research that develops this issue on case studies from different disciplinary perspectives includes:
Teruggi et al. proposed an end-to-end framework to deliver mixed reality experiences for large cultural heritage starting from high-resolution 3D survey data, emphasising the semantic segmentation process (Teruggi et al., 2021). Franczuk et al. presented the implementation of direct use of raw point cloud data enriched with digital historical resources to create real-time virtual interaction in a PC application powered by the Unreal Engine in the case of Kłodzko Fortress (Franczuk et al., 2022). Neuman-Donihue et al. proposed a plugin for rendering massive, unordered clouds in various file formats integrated with the Unity platform (Neuman-Donihue et al., 2023).

2. CASE STUDY

2.1 Ghesc: The Village Laboratory

North of the remote Ossola Valley in Montecrestese (Figure 1), a small medieval village called Ghesc was long kept secret (Figure 2). Almost ten years ago, as part of the "Villaggio Laboratorio" project initiated and sponsored by the Canova association, numerous structures on the site that had been abandoned for almost 100 years were started to undergo repair. In order to protect, restore, and promote the stone architecture, the objective is to reinvigorate the village by merging public and private spaces through field schools and research activities (Cesprini and Marquardt, 2020). The ambitious goal also includes figuring out the best approach to demonstrate to a wider audience how the town has evolved over time due to building restoration efforts.

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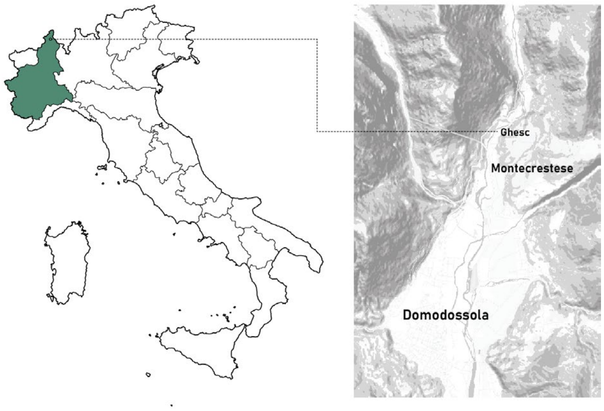

Figure 1. The location of Ghesc village.

Figure 2. Ghesc village.

2.2 Survey Summer School “The Laboratory of Places”

From 2011 to 2017, the 3D Survey Group at Politecnico di Milano conducted an annual summer school program, “The Laboratory of Places”. This program cultivated a cooperative environment among students, teachers, members of the Canova Association, and the local community (Achille et al., 2022). The initiative aimed at contributing to the documentation of vernacular architectures in the Ossola region as well as promoting the learning of advanced survey techniques (Achille et al., 2018), which includes:
i. Topographic Instrument: surveying and data processing.
ii. Laser Scanner Tools: acquisition and management of the point cloud and elaboration of floor plans, sections, profiles, and 3D models.
iii. Photogrammetric Survey: terrestrial (digital camera) and aerial (Drones) acquisitions, standard photogrammetric workflow (internal/external orientation, image matching, orthophoto, and 3D model production).
iv. Structured Light Scanner: survey of small objects, mesh processing, and 3D model production.

Over the years, the summer school has employed tethered balloons (2012) and UAVs (2013-2017) for aerial surveys. In the most recent edition, students had the opportunity to exploit advanced scanning technologies such as the Leica portable scanners BLK 360 and Pegasus Backpack on the ultimate objective. The methodology is determined by factors like the level of detail required, the features of the object being studied, and the surrounding environment. It’s feasible to blend various processes and tools, utilising them together to create a final “hybrid” product that meets the specified requirements. Additionally, merging different techniques enables the optimisation of data collection and processing stages by capitalising on the best aspects and capabilities of each tool.

Survey activities conducted throughout these years have served as faithful documentation for the recovery project of the abandoned village. The point cloud data derived from these activities can be seen as “time slices”, capturing various stages of the restoration and rebuilding interventions in Ghesc. Simultaneously, they document the evolution of 3D survey tools. This process has paved the way for the creation of a digital archive, providing a comprehensive view of the village’s historical structures at differing preservation stages. Consequently, this archive presents a valuable resource for researchers, historians, and restorers in monitoring, managing, and promoting the architectural heritage of the Ossola Valley.

2.3 Narrating Ghesc: A Point Cloud-Based Multiplatform Application

This research introduces “Narrating Ghesc”, a point cloud-based multiplatform application developed to support the conservation project, leverage survey data, and deliver the hidden Ghesc and its history to a broader audience (Figure 3-4). This program includes a PC/Web platform as a digital archive of the preservation project for professional uses, a field-use mobile AR application to enhance on-site experiences for visitors, and a VR exploration of the village in various years between 2011 and the present, with the addition of various types of content, including maps, 2D technical drawings, photographs, video interviews, and historical documentation. The program presents the village using the point cloud models acquired from the survey activities. This application not only provides the users with an opportunity to navigate the village freely but also allows them to discover Ghesc’s secrets through gamified immersive and interactive experiences such as time travelling and virtual restoration.

Figure 3. A scheme for the Narrating Ghesc application.

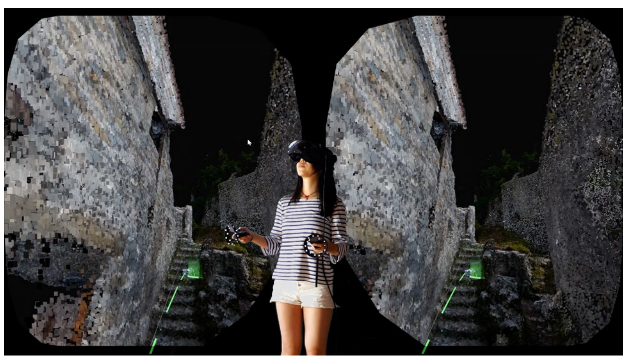

Figure 4. A scene in the Narrating Ghesc VR application.

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3. DATA REPRESENTATION

Many heritage sites and museums have implemented both on-site and off-site playful learning experiences to boost public engagement. In most cases, low-poly 3D reconstructed models with high-fidelity textures derived from 3D surveys are employed to visualise and represent cultural heritage. This method strikes a balance between accurate reality-based representation and optimal operational performance. However, converting raw survey data to mesh involves specialised computer and software tools and a level of complexity that can be time-consuming, even for expert users. Consequently, this method is primarily employed for prestigious cultural heritage. Alternatively, some heritage sites and museums offer immersive virtual tours featuring 360-degree panoramic photos or videos. While this content is relatively easy to acquire, creating interactive experiences upon it can be challenging, with full immersion difficult to achieve. Crafting a simplified geometric model is a viable option when targeting younger users, and authenticity is not the primary concern. Taking into account the advantages and disadvantages of the aforementioned methods, the authors of this paper proposed an innovative approach using processed point clouds for heritage representation and digital access. This method holds significant potential to streamline the virtual reconstruction process while maintaining visual quality.

As Figure 5 shows, the proposed working pipeline from survey to representation contains four phases: (1) data acquisition, (2) data processing, (3) data elaboration, and (4) data visualisation. Each phase includes various steps and is carried out using different hardware and software devices. The data acquired in 2023 in a mobile mapping survey will be used as an example to explain the steps and the reasons behind them.

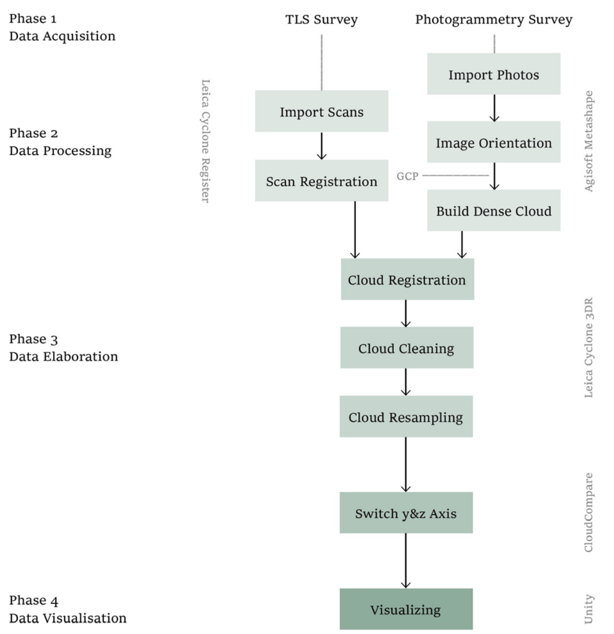

Figure 5. The working pipeline for data representation.

Mobile mapping is the process of acquiring geospatial data from a mobile platform (Puente et al., 2013), which could be a vehicle, a robot, or a drone. This survey method enables rapid data acquisition for large areas for architectural surveys as well as other spatial documentation tasks and can be adapted to various environments. The handheld imaging laser scanner Leica BLK2GO (Leica Geosystems, 2023) was used in the on-site mobile mapping survey in the year 2023 for the Ghesc village. It utilises the combination of LiDAR technology, SLAM, and imaging sensors to capture 3D point clouds and panoramic images of indoor and outdoor environments. As the surveyor walks through the space, the BLK2GO creates a real-time 3D digital twin of the area.

A total of 10 paths were performed in Ghesc, and 10 point models were generated. The scans were registered using the software Leica Cyclone Register through the following steps: import scans, review the raw on-site registration (the automatically generated suggested links), manually create and optimise links, check the error statistics and finalise, report and publish. To achieve a satisfactory visual result in the application as well as maintain an acceptable operating performance, the registered point cloud needed to be further processed.

The goal was to obtain a cloud with approximately 15,000,000 points while keeping the details and colour information for architectural elements as clear as possible. In order to reach this goal, unwanted objects, such as moving people and light rays, had to be cleaned, and the points needed to be significantly reduced.

Since the multiple overlapping and the different light conditions of the clouds would impact the visual quality of the outcome, three solutions were carried out and examined: (1) a merged cloud from 10 registered paths acquired between 14:50 and 19:40; (2) a collaged cloud from 5 registered paths of the village acquired between 14:50 and 15:50 with minimum overlapping parts and changes of light conditions; (3) a single complete path acquired at 19:40. These three solutions were later examined in CloudCompare and the collaged cloud was determined as the best solution for the representation in the application. Instead, the merged cloud (1) shows more noise than the collaged cloud and gives a blurry visual effect.

The data elaboration phase was carried out using the software Leica Cyclone 3DR. The key action to create a collaged cloud is to identify the best scan for each building or area from the five selected clouds and separate them with a clipping box. Later, the same clipping box can be used again to delete the overlapping parts in the other clouds. Through this method, an optimised cloud with fewer points was generated. Further post-processing actions include cleaning and reducing/resampling.

The fastest and simplest solution would have been to equally reduce the entire cloud using the reduce/resample option in Leica Cyclone 3DR or the subsample option in CloudCompare (open-source software) to obtain a cloud within the predefined point threshold. However, since the level of detail required for different elements varies, the preferable solution is to divide the point clouds according to the types of elements. In order to apply different resampling rates and achieve the different desired levels of detail, the point cloud for Ghesc was separated into three parts: the vegetation, the ground, and the buildings (Figure 6).

After obtaining a reduced cloud, an additional step has to be carried out in CloudCompare to switch the y and z axes because the coordinate system in Unity is different from the software previously used. The elaborated point cloud, stored in PLY binary format, was imported into Unity using "PCX" (Keijiro, 2023), a free custom package for visualising and handling point cloud data with the feature to adjust point size and brightness.

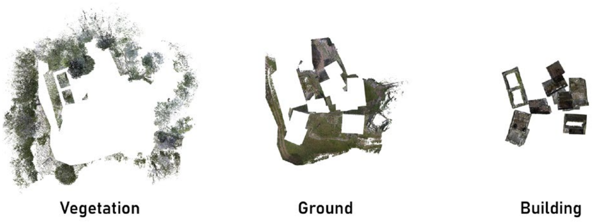

Figure 6. Separating different elements before resampling.

4. VISUAL QUALITY ASSESSMENT

Without any doubt, the proposition of using a point cloud instead of a mesh can greatly streamline the procedures for the 3D representation of cultural assets in a virtual environment. However, it poses the question of how this shift will impact the visual quality. To address this, both a high-poly and low-poly mesh for the year 2017 data have been created to be compared with the optimised point cloud data.

4.1 Mesh Building and its Simplification

The Scan-to-Mesh feature in Leica Cyclone 3DR enables simple conversion from a point cloud to a textured mesh. The mesh model could be generated with a range of detail settings adapted to different Leica laser scanners. High-poly mesh objects with complex geometrical details do not yield suitable results for real-time visualisation applications. This is mainly due to the requirement of a system with substantial memory and computational power. The retopology process is necessary to make such models interactable on an average user's device, particularly on mobile platforms and virtual reality (Gradusova, 2022). This process considerably simplifies an object's geometry and decreases the mesh polygon count. While manual refinement offers higher-quality results, this study employed the method of automatic re-meshing. Tailoring a new topology based on an existing one manually demands advanced 3D modelling skills.

The software Instant Meshes was identified as the most suitable automatic retopology program in this study (Figure 7). The process involved importing the high-poly model in the OBJ format and then choosing the polygon shape - Quads - in the Remesh section. The reason for choosing quadrilateral over triangular mesh is its natural advantage to better capture the local principal curvature directions or sharp features. Since there are two logically orthogonal directions (u and v) for the surface, quads can be designed to follow these isoclines, producing meshes that reflect the underlying geometry (Docampo-Sanchez and Haimes, 2019).

Moreover, its rectangular grid topology naturally matches the sampling pattern of textures, making it suitable for texturing and compression. The Target Vertex Count scale was then used to assign the desired number of vertices based on the level of detail we wanted. Even though retopology's primary objective is to create a model with fewer polygons, the object's shape needs to remain distinguishable. For the 2017 cloud, the value was set at 32k. In the first instance, the preliminary direction of polygons was computed (Solve tool). In a second step, the mesh was then optimised (Solve tool in the Position Field section). Finally, the Extract Mesh option was chosen to convert the 3D model into quads, ending the process and readying the object for further work.

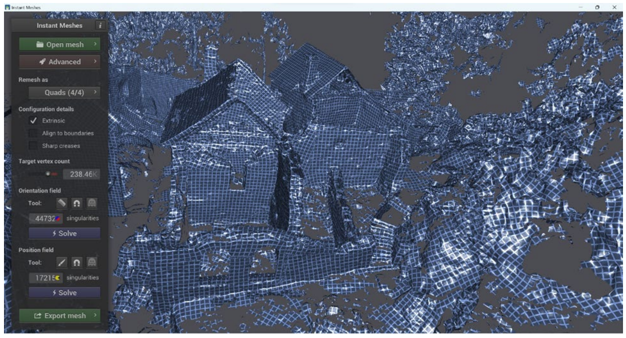

Figure 7. Mesh simplification in Instant Meshes.

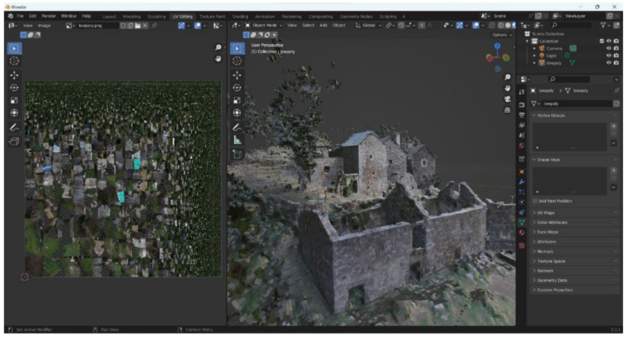

Figure 8. Texture baking in Blender.

The software Blender was then employed to bake a texture from the high poly model to the obtained low poly model (Figure 8). The process started with importing the high-poly generated in Leica Cyclone 3DR and the low-poly mesh created in Instant Meshes into Blender, making sure they were overlaying each other in the same position. The high-poly model could be turned off to allow better speed. Then, a new image was created in the UV editing workspace with the following parameters to bake a 4k texture: width: 4096 px; height: 4096 px; generated type: colour grid. In the Shader Editor, a node Image Texture was added with the newly created pattern as a data block inside. Thus, the temporary UV texturing of the 3D model was set.

The following step was UV unwrapping. UV unwrapping is the process of flattening a 3D model into 2D by cutting along seams to accurately apply a texture. After entering the edit mode and enabling the face selecting mode, all polygons were added to the selection (key A) before carrying out the UV unwrap command in the dropdown, which would automatically map the 3D model's vertices to a 2D plane. The final step was to bake the texture from the high-poly mesh. In order to perform this operation, the high-poly model was turned on and selected first, and then the low-poly model was added to the selection. The low-poly model would be highlighted with a brighter outline, implying it is the active object. The next action was carried out in the Render Properties window. The render engine was changed to Cycles and the Bake Type to Diffuse. The direct and indirect lights were turned off since the lighting was not a part of the texture. The Selected to Active option was turned on, and the Extrusion was adjusted to 0.1m so the baked texture would be applied to the active object, which was the low-poly model. Upon clicking the Bake button, a texture created from the high-poly mesh was added to the low-poly mesh. After saving the texture as an image and exporting the textured low-poly model, the reduced point cloud, high-poly, and low-poly mesh were imported into CloudCompare for examination.

4.2 Assessment in CloudCompare

To comprehensively assess the visual quality between two contrasting methods, two scenes - an overall view of the entire village and a detailed close-up of façade work – were selected to evaluate. The point cloud version required a dual evaluation, utilising smaller and larger point sizes to demonstrate the potential of using points as the render primitive. The first evaluation is shown in Figure 9. In this scene, the cloud with smaller point sizes portrayed Casa del Prete and Casa Alfio with an unusual X-ray effect (bottom left corner) due to its translucent representation. This method highlighted the variable density of the cloud sections, thereby directing focus towards the central structures of Casa dell'Associazione and Casa dell'Affresco. Enlarging point size removed basically the gaps between points, resulting in a rather solid surface display of all structures. However, the mesh models provided the clearest depiction of Casa del Prete's façade, vividly presenting its decay and faded features, which were somewhat concealed by gaps in the point cloud representation.

It is worth noting that the mesh models lacked refinement and optimisation, resulting in varying sizes of visible voids and gaps, most notably in the main open space where the original points were sparse. Compared to the point cloud representation, which allowed for a seamless transition between dense and sparse areas, the abrupt shifts from solid surfaces to empty voids in mesh models were too stark to ignore. This pointed to the necessity of an additional step to fill these voids and refine the model if the mesh solution was chosen for cultural heritage representation in a virtual application. Furthermore, the brightness of the point cloud could be adjusted by modifying the point colour settings; instead, it could be accomplished in the mesh model through adjustments to the environmental lighting settings. The background depiction of trees was considered satisfactory in both methods for this scene.

The second scene, as Figure 10 shows, was selected specifically to contrast the depiction of stone facades upon closer inspection. When the point size is configured to 1 in CloudCompare, viewers can visually penetrate the facade.

Figure 9. Visual quality assessment – Scene 1.

Figure 10. Visual quality assessment – Scene 2.

This ability allows them to perceive the depth of the building and even distinguish its structural elements. Here, the depth and complexity of the architectural edifice become discernible, enriching the viewing experience. Equally impressive in their portrayal of the rough texture of the stone façade is the point cloud with a larger point size and the high-poly mesh. Both versions bring to the fore the visceral quality of the stone, its weather-beaten, rugged aspect contributing to the overall aesthetic appeal. On the other hand, in the low-poly mesh, the texture appears less defined, seeming almost like an image affixed to a flattened surface. The lower resolution of the low-poly mesh pays a price in terms of texture representation, hereby affecting the level of authenticity and richness in the outcome. The less detailed texture in this version can downplay the raw appeal of the stone façade, diluting the immersive visual experience.

4.3 Discussion

Both mesh and point cloud models have their strengths and weaknesses in representing complex cultural heritage sites. Mesh models, with their clean and defined structure, are particularly effective in representing specific, tangible details, such as the texture of the stone façade or the distinct features of architectural artifacts. However, their limited flexibility and high demand for refinement and optimisation can make them time-consuming and cumbersome to work with, particularly in cases where precise representation and reconstruction of complex or irregular structures are required. For example, the stark contrast between solid and void areas in mesh models can distract viewers from the overall representation, and the visible gaps and voids often require additional steps to fill and correct.

Point cloud models, on the other hand, allow for a more abstract and flexible representation. They are particularly effective in handling complex or irregular scenarios and can provide a more immersive and engaging experience for viewers. However, they may not provide as detailed a representation as mesh models, particularly for specific architectural features or textures in close observation. Point clouds are generally very effective for representing a scene and its context, less so for a specific architecture. Their abstract nature can also lead to an ambiguous representation in certain frames or views.

Overall, while both methods have their pros and cons, the use of point cloud models could be a game changer in the representation of cultural heritage sites in virtual applications, largely for their flexibility, scalability, "ready-to-use" and the immersive viewing experience they provide. This is evident in the case of the Ghesc project, where the use of point cloud models significantly streamlined the 3D reconstruction procedures and provided a more engaging and immersive virtual representation of the village. Despite potential issues with visual quality and detail, the fact that point cloud models can be easily post-processed and updated with new data without having to remodel the entire entity makes them a more practical and efficient solution for representing such complex and extensive cultural heritage sites.

5. APPLICATION PERFORMANCE OPTIMISATION

As concluded, using point clouds instead of mesh models to represent cultural heritage could significantly simplify the virtual reconstruction process while obtaining a high level of detail and ensuring the overall visual quality. However, there is another crucial aspect that affects the performance of an immersive and interactive virtual application that must be taken into consideration by developers: the frame rate. Previous research has shown that frame rate has a much greater impact on user performance than resolution across all game perspectives and gameplay actions. A smooth visual experience, provided by high frame rates, significantly enhances the degree of immersion of the application. Generally, movements start to appear jittery if the frame rate drops below 30 frames per second, thereby interrupting the immersive experience. Moreover, high frame rates ensure that user inputs are collected and processed instantly, which results in a fluid, real-time interactive experience. On the other hand, a low frame rate increases the lag between user input and visual feedback, which makes the application seem less responsive.

In virtual reality environments, a low frame rate can cause notable discomfort and motion sickness. Therefore, it is recommended to maintain a frame rate of at least 90 frames per second for VR applications (Tähemaa and Bondarenko, 2019). According to the principles of aesthetics, high frames per second elevate the perceived quality of graphics and animations. This is particularly fundamental for virtual heritage applications that aim to depict historical or cultural contexts with precision and authenticity. In some instances, the frame rate must also align with the refresh rate of external systems, such as VR headsets, tracking systems, or display screens, to avert visual artifacts such as tearing. Furthermore, elements like transitions, movements, special effects, and user interactions appear more lifelike at higher frame rates, which is crucial for user engagement and immersion in a virtual heritage application.

The choice of using point cloud over mesh in the design of a Unity application has notable implications on the frame rate. Large point clouds can consume significant memory, leading to slower processing and lower frame rates. Hence, two strategies have been implemented in the Ghesc project to optimise application performance.

5.1 Rendering Methods

The first approach entails evaluating different rendering techniques for point cloud and implementing the most efficient one. Two shaders offered by the PCX package were assessed in this process. The first available choice is the points primitive, a fundamentally simple approach for rendering points. Within this shader, each point is converted into screen space coordinates, ensuring that each point supplied to the GPU is rendered as an individual pixel on the screen.

Figure 11 illustrates this method of rendering. Although distant objects appear vivid, objects near the camera appear almost translucent due to low density. This can create an X-ray effect where viewers may see through facades, leading to potential confusion. Fortunately, certain graphic libraries, such as OpenGL, allow for setting a specific point size - this causes each point to be automatically rendered as a square of a given size in the world space. The limitation, however, lies in the fact that only certain platforms support this point-size property. Figure 12 demonstrates how adjusting the point size could rectify the issue of a transparent foreground. When operating the application on the HP OMEN gaming laptop with an NVIDIA GeForce RTX 3070 Ti Laptop GPU, the frame rate generally exceeds 30 frames per second for a point cloud of 15,000,000 point budget with a QHD screen resolution (2560x1440 pixels), which is a satisfactory outcome.

Figure 11. Point primitives shader without point size feature.

Figure 12. Point primitives shader with point size feature.

Figure 13. Applying smaller point sizes with disk shader.

Figure 14. Applying larger point sizes with disk shader.

However, it is important to note that a sudden change in the frame rate could negatively affect user experience. For instance, when the player uses the joystick to alter the camera orientation, the number of points displayed on the screen could fluctuate significantly. In this scenario, the camera’s rotation speed could accordingly shift, resulting in unstable movement that may cause motion sickness. This issue can be mitigated by adjusting the joystick’s sensitivity and imposing a frame rate limit.

As shown in Figures 13 and 14, the second option features point rendering as small disks via a geometry shader. In this context, each point is sent to the GPU once, and new points are constructed to form a screen-sized disk. The new points generated per input point are governed by the following line in the shader script, “Disk.cginc”: uint slices = min((radius + 1) / 5, 4) + 2 (a range between 2-6). This line can be modified to assign a fixed slice value. For instance, if the slice for every disk were set at 2, the points would be rendered as squares. This functionality permits alterations to the point shapes, resulting in different visual outcomes.

However, the average frame rate is noted to be lower in this rendering method (a range of 5-15) than in point primitive operating on the same device. The author hypothesises that, in this case, more triangles need to be processed since each point is essentially rendered as a small disk with multiple triangles. Nevertheless, with the benefit of the geometry shader, which GPU supports, this mode may offer more movement stability than the point primitives, provided operating on superior hardware. Instead, the point primitives allow a higher frame rate even on average devices due to fewer triangles.

Additionally, the geometry shader introduces the potential to interpolate. This strategy mitigates the downside of point overlap by merging nearby points, producing a more realistic visual outcome. Here, the predetermined point shapes lose prominence, enabling better preservation of texture details and structures. However, this potential enhancement demands additional shader computation and remains untested in this project.

In conclusion, both point shader and disk shader have their advantages and disadvantages when rendering a point cloud; however, for this project, point primitives were chosen due to their superior speed performance. Point primitives ensure a higher frame rate and a responsive interaction experience, an essential aspect of virtual heritage applications. On the other hand, the disk shader provides more richness in visual output but requires more intensive computation, which may lead to lower frame rate performance, especially on less capable devices. Nonetheless, this area warrants further research, particularly focusing on how to balance visual richness and performance efficiency to provide an enhanced user experience. Future investigations could experiment with promising concepts such as interpolating between points with a geometry shader for a more realistic visual outcome and frame rate stability whilst maintaining the performance’s efficiency. Moreover, employing a level of detail feature could prove pivotal in addressing frame rate issues. This approach would allow for adaptive resolution of the point cloud data depending on the performance capability of the device and the position of the viewer, providing a dynamic way to improve visual quality without sacrificing frame rate performance.

5.2 Point Budget

Another strategy employed to optimise performance is the establishment of varying point budgets for diverse device types. Devices with superior GPU and heightened processing abilities, such as a PC, could benefit from a larger point budget to enhance visual quality. Conversely, lower-powered devices such as tablets might utilise a smaller point budget, reducing processor strain and thereby increasing frame rates and smoothing application operation. Considering tablets often have smaller screen sizes than PCs, reducing points is also justified visually. Maintaining an exceptionally high and consistent frame rate for a VR environment is essential to prevent motion sickness and ensure full immersion. As such, the point budget should be carefully adjusted to strike a balance between visual quality and performance capacity.

In the Ghesc project, the registered scan that covers the entire village might contain hundreds of millions of points. As discussed in the working pipeline, to reach the proposed point budget for each platform, every point cloud needs to undergo at least four post-processing steps: cleaning of valueless objects; simple classification of the points by the types of elements they represent; resample according to the priority levels of the elements; general reduction for the target device.

6. CONCLUSION

Digital technologies, in particular augmented reality and virtual reality, are shaping the future of cultural heritage promotion. They are not only making heritage sites and objects more accessible but also fostering a comprehensive understanding and appreciation of these cultural contents among audiences.

As the first product of 3D surveys, point cloud data provides an accurate and faithful representation of cultural heritage. This paper proposed an unconventional way to use point clouds directly as rendering assets to visualise complex cultural heritage in virtual applications across platforms. This method could significantly streamline the digital reconstruction process while obtaining a high-fidelity representation, which allows the developers to have a greater focus on other aspects, such as content curation and user experience design. The choice of using point clouds evoked a unique aesthetic quality that masterfully blends realism with abstraction. Compared to a mesh model, it is easier to apply different levels of detail to different elements and sections of a point cloud due to its flexible and abstract nature.

This feature has been proven advantageous in the case of Ghesc because it helps to emphasise the architectural structures while keeping a general perception of their important natural environment. Besides, the option to change the features of points, such as brightness and size, in the application provides different visual outcomes according to the user's preferences. Moreover, using point clouds allows updating the model with new data without the need to remodel the entire entity.

Despite the apparent benefits, challenges exist. Large point clouds for complex cultural heritage consume significant memory, leading to slower processing, which would be a drawback, especially in a VR environment where a high frame rate is essential to achieve full immersion. The authors of this paper anticipate further research into this issue to maximise the potential of point cloud data as direct rendering assets for cultural heritage representation.

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APPENDIX

A short video of the presented work is available at the following link: https://youtu.be/w5OCuEaeEEg?si=EwIy4GoGxUPVlj9f