Digital Heritage to Improve Accessibility and Break Down Architectural Barriers

Damiano Perri[1(✉)], Sara Martinelli[1], Osvaldo Gervasi[1], David Berti[2], and Gilberto Zinourov Roncalli di Montorio[2]

[1] Department of Mathematics and Computer Science, University of Perugia, Perugia, Italy
{damiano.perri,osvaldo.gervasi}@unipg.it
[2] ART S.p.A., Passignano sul Trasimeno, Perugia, Italy
{david.berti,gilberto.zinourov}@artgroup-spa.com

Abstract. This work aims to create a navigable virtual environment of the Bufalini Castle through virtual reality viewers, allowing the elimination of physical barriers and ensuring full accessibility to cultural sites. The majestic building, built during the 15th century, has an architectural conformation that is not easily accessible to people with mobility disabilities. The structure's design, featuring narrow passages, multiple staircases, and a lack of elevators, currently restricts exploration for visitors using wheelchairs or facing other mobility challenges. The creation of the 3D scenario mainly uses virtual reality technologies. However, to ensure a good level of realism, photogrammetry involves capturing extensive photographic datasets of the castle, which are then processed to create geometrically accurate and texturally rich meshes, capturing a high level of graphic detail and realism essential for an engaging user experience.

Keywords: Virtual Reality · Metaverse · Digital Twin · Cultural Heritage

1 Introduction

The Bufalini Castle is located in the small town of San Giustino, in the province of Perugia, in the Upper Tiber Valley. It is one of the very few historic stately homes that has remained intact, in fact, inside it is still possible to find most of the decorations and furnishings dating back to the period between the 16th and 20th centuries. The Castle also boasts a fantastic surrounding park, consisting of an 'Italian-style' garden with lemon groves, fountains and a labyrinth. Taking into account the Castle's conformation, the fact that it is a historical asset whose structure is difficult to modify, and the fact that it is of great cultural interest, it was chosen as a use case to improve accessibility through modern Virtual Reality technologies.

Virtual Reality (VR) allows the creation of simulated environments through the use of a computer or other devices like smartphones, tablets and headsets.

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2026
O. Gervasi et al. (Eds.): ICCSA 2025, LNCS 15898, pp. 229–241, 2026.
https://doi.org/10.1007/978-3-031-97657-5_14

This is an immersive technology, i.e. one that can interactively involve the user projected into any 3D location, and through the use of special devices the user can interact with the environment. These devices can be standard input devices such as a keyboard and mouse, or multimodal devices such as a wired glove and/or an omnidirectional treadmill. Thus, users interact with virtual 3D objects in real time in an intuitive and natural way, perceiving them as real and coming to understand, analyse and communicate. It allows for first-person adventures and experiences, breaking down geographical barriers and simulating any setting. It stems from the idea of replicating reality as accurately as possible visually, audibly, tactilely and even olfactively, in order to perform actions in virtual space that are difficult or impossible to emulate in the real world, overcoming physical, economic and security limitations.

This approach becomes even more crucial, happening in this time of fast-paced evolution of all digital ecosystems around us, where the interaction with information acquires new layers and stratifications of complexity, which dictates the necessity for adopting technologies which grant always more immersive and accessible user experiences. Immersivity which should safeguards both searching for information and infering, retrieving or discovering information in a specific informative or spatial context, where clues can be structured to grant sensemaking and proper content understandability [1].

Virtual reality succeeds in creating virtual environments and experiences using a combination of hardware (e.g. wearable visors, tracking systems, graphics processing) and software (i.e. web-based or local applications).

The strength of this technology lies in the fact that it makes the virtual environment feel similar to the real world. Hence, the subject goes from being an observer of an action to becoming its protagonist, able to see, hear, manipulate objects that do not exist, travel through spaces without a place in the company of people who are elsewhere. This active process of interaction with the virtual world produces the sense of presence, i.e. the feeling of being in the virtual environment [2].

The use of virtual reality has many advantages, for example it offers the opportunity to experience various situations without the need to physically create them, reducing costs and risks [3].

2 Related Works

The evolution of architecture has always been conditioned by technological innovation; indeed, it is digital technology that progressively brings buildings and places to life. This has led to the design of buildings with a multi-sensory approach, i.e. involving other senses besides sight, particularly in museums. The difficulty arises when trying to reconstruct the 3D model of historical and archaeological objects and monuments in their current condition. Methodologies that generate precise geometry and a very high level of realism are required. Currently, there are tools that allow sophisticated processing such as laser scanning of the landscape, automatic orientation and measurement operations, and the generation of digital orthoimages [4].

Virtual environments created from images have the exact same characteristics as 3D models created with modelling software, so it will be possible to manipulate, navigate and enrich them with important information and data of a different nature, such as text and audio, useful for better describing the object under examination [5]. Photogrammetry is a technique that reconstructs 3D models from a set of photographs taken on purpose [6]. The results have a very high quality that could hardly be achieved by manually recreating objects and textures. The difficulty of this technique concerns the large number of vertices and faces that are created, so the limitation is the computational power of the machine used to process the images [7].

Today, the use of GPUs has greatly increased the level of available computational power, allowing the creation of very complex models in a short time. GPUs are extremely important for AI [8,9]; they are used for training large language models, but they are also needed for generating 3D scenarios and running computer graphics applications such as video and serious games [10,11]. Each image is divided into many adjacent polygons to form faces, the number of which depends on the degree of realism and quality of the result [12]. This technique is very useful in cases where manual modelling of polygonal details is complex and the result unsatisfactory, photogrammetry allows a very high level of realism by exploiting artificial intelligence techniques for the realisation of the most complex parts.

The photographs to be used as a dataset of images to realise the model must be of a sufficiently large number to cover all the angles of the object, and there must be a certain level of overlap to ensure a homogeneous mesh without holes. The ideal overlap percentage is around 70 per cent. The degree of confidence in the final result depends mainly on the photographer's ability to set the right parameters according to environment, light and subject. It is crucial to make sure that the entire photo set has the same focal length and lighting.

The drone used is a DJI MINI 3. This is a compact and ultra-light camera drone with a foldable design and a weight of less than 249g. It allows 4K HDR video and has an extended battery life that can provide a maximum flight time of up to 38 min. The camera used for shooting is equipped with a 1/1.3-inch CMOS sensor, the focal length is 6.7 mm, the aperture is fixed at f/1.7, exposure time is 1/320 with ISO 100, color space sRGB. The resolution of the camera is 4000×2250 pixels (9.0 MegaPixels).

Figure 1 shows the steps in the reconstruction of the castle. The work was divided into four stages: the first stage was the inspection and analysis of the building with the support of the castle staff, the second stage involves taking photographs with the drone with the preset shooting parameters, the third stage involves reconstruction by photogrammetry using the open source software OpenDroneMap[1], and finally the fourth stage involves obtaining the 3D model and its optimisation using Blender[2].

[1] https://opendronemap.org/.
[2] https://www.blender.org/.

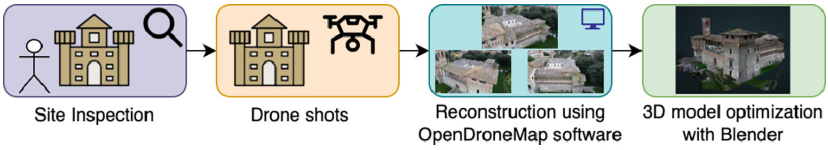

Fig. 1. Phases in the photogrammetric reconstruction of a castle: from survey to 3D model.

The amount of photography required is proportional to the size of the object [5]. In addition to photogrammetry, LiDAR technologies are often used. This is a sensor that fires a pulse of infrared light at an object and is able to detect the distance by calculating the time it takes for it to bounce back to the sensor [13]. In recent years, LiDAR has developed in the field of 3D scanning for smartphones. Now present in the latest IOS devices, it provides a longer-range capture than is possible with Face ID [14]. By analysing the time and power of the laser pulse bounce, LiDAR devices can generate dense point clouds that accurately capture the details of scanned objects. This allows LiDAR to capture 3D space in real time, thus benefiting time and resolution. The calculations required to create the 3D models generated by scanning real-world scenarios can also be done in the cloud; in fact, there are services that researchers can use to leverage computational power for a fee, such as Matterport[3] [15–18].

Virtual reality applications can then be integrated within complex environments in order to implement metaverses, i.e. multi-user interactive scenarios that can allow the creation of immersive experiences, also from a social point of view [19]. The metaverse applied to tourism can, in fact, be understood as an environment where tourists can first experience the place to be visited, building expectations while breaking down physical and temporal barriers [20].

3 Discussion

After having undertaken a complex study of the best technologies in use today for the realisation of Digital Twin, especially in the architectural field, taking into account the characteristics of each one and the various difficulties of the subject to be reproduced, the methods of project development were defined. Given the size of the subject to be represented, manual reproduction is difficult, so it is appropriate to make use of the technique of photogrammetry. This technique, thanks to the use of Artificial Intelligence algorithms, makes it possible to achieve very high performance results in a short time, with a high level of detail and photorealism.

First of all, a survey was made of both the exterior and interior of the castle. The exterior was recorded in the form of photographic and videographic documentation using a professional drone. Figure 2 shows a detail of the castle, seen

[3] https://matterport.com/.

from the outside, taken by the drone. Figure 3 shows the castle and the drone mapping the exterior surface.



Fig. 2. Aerial view of the castle taken by drone

By analysing the interior of the castle, the three main rooms were identified, which were then the subject of the computer graphics reconstruction procedure.

- **Il Salone**, *The Hall*: is located on the ground floor, therefore relatively easily accessible to all, but worth reproducing virtually given its beauty and size. This room also serves to demonstrate the power of this technology in large and detailed environments.
- **La camera degli Dei pagani o di Giove**, *The chamber of the pagan Gods or Jupiter*,: we find it going up the first ramp of the staircase, therefore inaccessible to those with motor disabilities, as it is impossible to install equipment such as lifts or platforms. This is one of the rooms open to the public, which would therefore generate inequality between people.
- **La Camera di Apollo**, *The Chamber of Apollo*: going up to the top floor of the donjon, exactly above the previously mentioned room, we find this room, which has been open to the public for a few months, but is absolutely inaccessible for those with mobility difficulties, given the three flights of stairs that have to be tackled to reach it.



Fig. 3. Exterior view of the castle with detail on the drone being mapped

3.1 Reconstruction of the Interior

To create the virtual environment of the interiors, it was necessary to take 360-degree photographic scans of fixed rotation points. The software used was Matterport. Therefore, as a first step, the room was scanned to take a series of surveys in order to cover the entire surface, maintaining a maximum distance of about three steps between scans. The device to be used for scanning had to be equipped with the LiDAR sensor, which can calculate distances and depths by exploiting the bounce time of light on objects. For greater accuracy it was necessary to keep the scanning device, which in my case was the cell phone, as still as possible. To do this, a tripod was used, which allowed for rotation while maintaining the same starting point and height.

Thirteen consecutive scans were required for the reconstruction of the living room, as it is the largest and most complex room.

The living room scan was the one for which the most time was spent. A total of thirteen consecutive scans were made, following a line that started from one of the room's entry points and then continued by circling around the large dining table and back to the starting point.

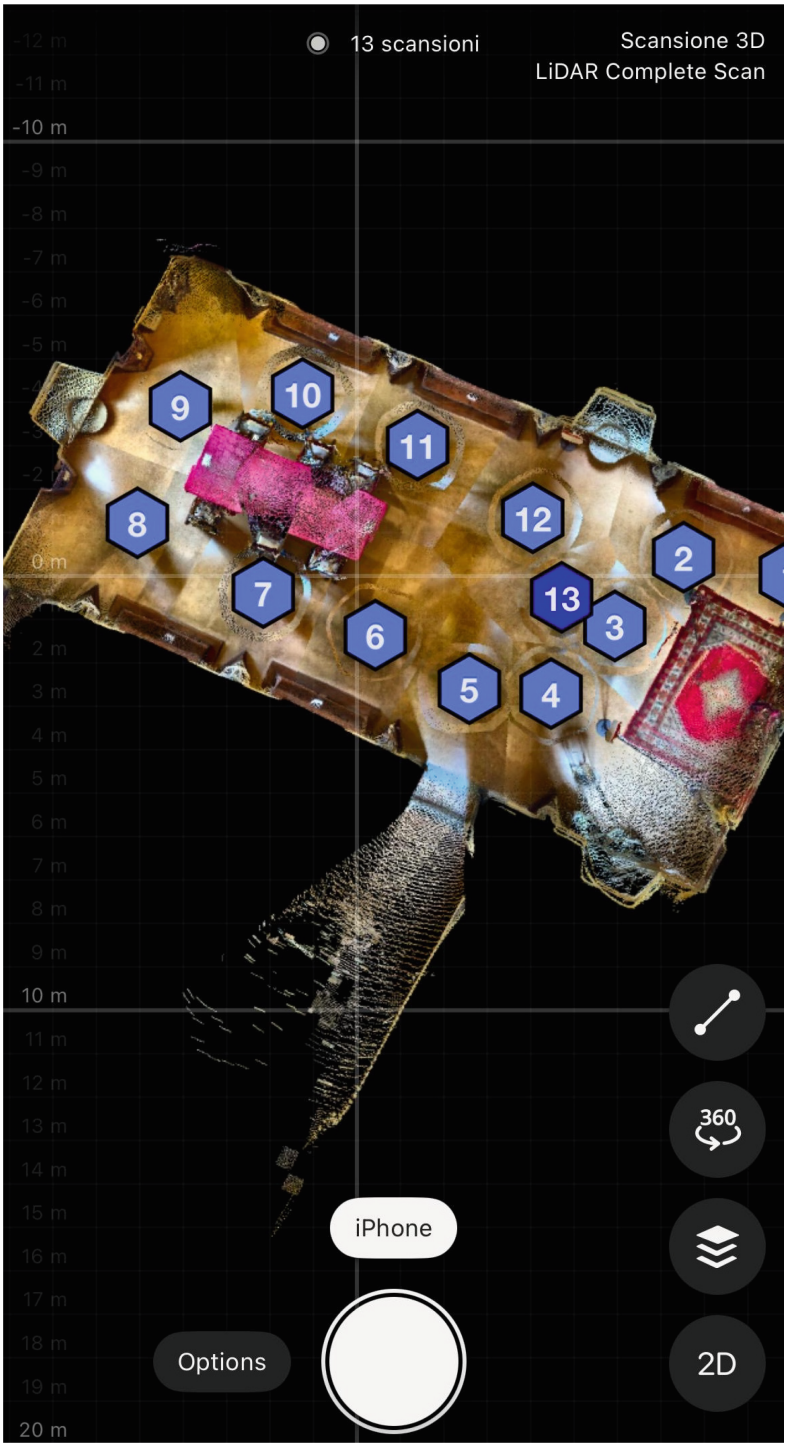

Fig. 4. Scans made in the hall of Bufalini Castle

The Pagan Gods Room Scan, on the other hand, took less time because it is a smaller room, so the number of frames to be captured and modeled was greatly reduced.

Figure 4 shows the result of the scans in the hall of Bufalini Castle. The environment is faithfully reproduced, with all the details and decorations present in the room and the user can move around the room, observing the environment from different angles and heights.



Fig. 5. Result of the scans in the hall of Bufalini Castle

Once the scanning process was completed, all previously processed work could be found in the application, with the option of uploading to the Cloud, for matching with the bespoke account and processing the work to create the virtual environment. The upload phase does not have a well-defined time, because it varies depending on the number of scans and details that the program needs to reproduce. The time required for the processing of the scans is about 24 h, after which the virtual environment is ready for use.

3.2 Reconstruction of the External Environment of the Castle

The external environment of the castle was reconstructed using a drone. The drone was equipped with a camera capable of taking high-resolution photographs, which were then processed by a software that created a 3D model of the castle. The drone was flown around the castle, taking photographs from different angles and heights, to ensure that the entire surface was covered. The

photographs were then processed by the software, which created a 3D model of the castle. Figure 6 shows the drone used to capture the photographs of the castle. The 3D model was then imported into a virtual reality environment, where it could be explored by users. The virtual reality environment allowed users to explore the exterior of the castle, as if they were actually there.



Fig. 6. Drone used to capture photographs of the castle

Figure 7 shows the 3D model of the castle, which was created using the photographs taken by the drone.



Fig. 7. The castel reconstructed in 3D

4 Conclusions

After a detailed study and testing of the best technologies currently available for the virtual reproduction of complex environments, the most suitable methodologies were defined to fulfill our goal, i.e. to break down physical barriers and ensure accessibility to cultural heritage even for people with walking difficulties or financial difficulties that prevent them from making long journeys and physically demanding trips. In this regard, thanks to the use of a combination of technologies such as virtual reality and photogrammetry, using devices such as smartphones equipped with the LiDAR sensor and drones, it was possible to recreate the environments in an extremely faithful and detailed manner. The cultural asset that was chosen as the subject of representation was the Bufalini Castle, a building of extreme beauty and a place of excellence from a cultural point of view for the area of San Giustino, a small town in the center of Italy.

The work was divided into two main parts, the first concerning the development of the interior and then that of the exterior of the building, which presented different characteristics and difficulties of execution. For the interior, three of the castle's rooms, significant for their beauty and accessibility, were reproduced. The technology used, through the LiDAR sensor, made it possible to recreate extremely realistic environments that guarantee an immersive visit to the areas, which would otherwise be inaccessible. With regard to the exterior, on the other hand, a 3D model of the building was reconstructed through the use of drone scans, which make it possible to faithfully reproduce large subjects that would

be difficult to reproduce manually. The work carried out is therefore very important to ensure that the level of accessibility of the cultural asset is raised, as well as a great opportunity for the dissemination of culture, mitigating inequalities between people.

A possible future development could be the addition of virtual tours in all areas of the Castle inaccessible to the disabled. For example, an interactive totem could be placed at the base of each staircase. The combination of physical and virtual tours would create a mixed environment, which would still safeguard the interest in physically visiting the Castle, while allowing everyone to visit it in its entirety. It would also allow the Authority to visit those rooms that are not yet open to the public for security reasons or architectural problems, greatly reducing the costs of making them safe and physically accessible. To make the experience extremely immersive, the museum could equip itself with devices such as visors and set up interactive guided tours. This could bring in a younger public, who are fascinated by technology and in a spirit of gamified entertainment can learn cultural notions and become passionate about environments they would not otherwise have considered. This is therefore a very useful starting point for possible future projects that will benefit citizens.

Acknowledgments. We would like to thank the staff of Bufalini Castle for their crucial support and for allowing us access for photographic footage and drone scanning of the exterior. We would like to thank the Davide Piampiano committee (https://www.comitatodavidepiampiano.com/) for providing some of the hardware needed for the work. With this research, we are carrying forward Davide Piampiano's vision for sustainable and digitised tourism.

References

1. White, R.W., Shah, C.: Panmodal information interaction. Commun. ACM **68**(4), 33–36 (2025). https://doi.org/10.1145/3701534. ISSN: 0001-0782
2. Zhang, Z., Wang, C., Weng, D., Liu, Y., Wang, Y.: Symmetrical reality: toward a unified framework for physical and virtual reality. In: 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pp. 1275–1276 (2019). https://doi.org/10.1109/VR.2019.8797970
3. Liu, Y., Sun, Q., Tang, Y., Li, Y., Jiang, W., Wu, J.: Virtual reality system for industrial training. In: 2020 International Conference on Virtual Reality and Visualization (ICVRV), pp. 338–339 (2020). https://doi.org/10.1109/ICVRV51359.2020.00091
4. Poullis, C., You, S., Neumann, U.: Rapid creation of large-scale photorealistic virtual environments. In: 2008 IEEE Virtual Reality Conference, pp. 153–160 (2008). https://doi.org/10.1109/VR.2008.4480767
5. Gervasi, O., Perri, D., Simonetti, M., Tasso, S.: Strategies for the digitalization of cultural heritage. In: Gervasi, O., Murgante, B., Misra, S., Rocha, A.M.A.C., Garau, C. (eds.) Computational Science and Its Applications – ICCSA 2022 Workshops, pp. 486–502. Springer, Cham (2022). ISBN: 978-3-031-10592-0

6. Sindayihebura, A., et al.: Monitoring land degradation using drone photogrammetry for the Mugoboka (Eastern Bujumbura, Burundi) case study. In: IGARSS 2024 - 2024 IEEE International Geoscience and Remote Sensing Symposium, pp. 1607–1609 (2024). https://doi.org/10.1109/IGARSS53475.2024.10641664
7. Daniel, M.X.S., Appadurai, N.K., Suan, W.B.: Enhancing realism and creativity in video/filmmaking utilising photogrammetry assets in CGI environments. In: 2023 IEEE 21st Student Conference on Research and Development (SCOReD), pp. 369–378 (2023). https://doi.org/10.1109/SCOReD60679.2023.10563856
8. Tamilarasi, T., Muthulakshmi, P.: Machine vision algorithm for detection and maturity prediction of Brinjal. Smart Agric. Technol. **7**, 100402 (2024). https://doi.org/10.1016/j.atech.2024.100402. ISSN: 2772-3755
9. Vella, F., Cefal, R.M., Costantini, A., Gervasi, O., Tanci, C.: GPU computing in EGI environment using a cloud approach. In: 2011 International Conference on Computational Science and Its Applications, pp. 150–155 (2011). https://doi.org/10.1109/ICCSA.2011.61
10. Perri, D., Fortunelli, M., Simonetti, M., Magni, R., Carloni, J., Gervasi, O.: Rapid prototyping of virtual reality cognitive exercises in a tele-rehabilitation context. Electronics **10**(4), 1–16 (2021). https://doi.org/10.3390/electronics10040457
11. Perri, D., Simonetti, M., Gervasi, O.: Deploying serious games for cognitive rehabilitation. Computers **11**(7) (2022). https://doi.org/10.3390/computers11070103. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85133209387&doi=10.3390%2fcomputers11070103&partnerID=40&md5=5c8b784acf53e7c9573a05e80e9480bc
12. Santucci, F., Frenguelli, F., De Angelis, A., Cuccaro, I., Perri, D., Simonetti, M.: An immersive open source environment using godot. In: Gervasi, O., et al. (eds.) ICCSA 2020. LNCS, vol. 12255, pp. 784–798. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-58820-5_56
13. Guan, W., You, S., Neumann, U.: Recognition-driven 3D navigation in large-scale virtual environments. In: 2011 IEEE Virtual Reality Conference, pp. 71–74 (2011). https://doi.org/10.1109/VR.2011.5759439
14. Lease, B.A., Chiam, D.H., Lim, K.H., Phang, J.T.S.: Development of 3D scanned environment in virtual reality. In: 2023 International Conference on Digital Applications, Transformation & Economy (ICDATE), pp. 1–4 (2023). https://doi.org/10.1109/ICDATE58146.2023.10248625
15. Perri, D., Simonetti, M., Gervasi, O.: Synthetic data generation to speed-up the object recognition pipeline. Electronics **11**(1) (2022). https://doi.org/10.3390/electronics11010002
16. Cuijie, Y., Biyan, L.: Research on optimization strategies for GPU cluster cloud rendering virtual simulation resources. In: 2024 14th International Conference on Information Technology in Medicine and Education (ITME), pp. 392–395 (2024). https://doi.org/10.1109/ITME63426.2024.00084
17. Perri, D., Simonetti, M., Lombardi, A., Faginas-Lago, N., Gervasi, O.: A new method for binary classification of proteins with machine learning. In: Gervasi, O., et al. (eds.) ICCSA 2021. LNCS, vol. 12958, pp. 388–397. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-87016-4_29
18. Montella, R., et al.: Enabling the CUDA unified memory model in edge, cloud and HPC offloaded GPU kernels. In: 2022 22nd IEEE International Symposium on Cluster, Cloud and Internet Computing (CCGrid), pp. 834–841 (2022). https://doi.org/10.1109/CCGrid54584.2022.00099

19. Perey, C.: Interoperability is a fundamental requirement for the open metaverse. In: 2024 IEEE International Symposium on Emerging Metaverse (ISEMV), pp. 21–24 (2024). https://doi.org/10.1109/ISEMV63338.2024.00019
20. Perri, D., Di Blasi, S.R., Forlani, F., Gervasi, O.: Exploring the metaverse: opportunities for tourism and territorial development. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). LNCS, vol. 14825, pp. 141–153 (2024). https://doi.org/10.1007/978-3-031-65343-8_9