SCIRES it
SCIentific RESearch and Information Technology
Ricerca Scientifica e Tecnologie dell'Informazione
Vol 14, Issue 1 (2024), 251-264
e-ISSN 2239-4303, DOI 10.2423/i22394303v14n1p251

CASPUR-CIBER Publishing, http://www.sciresit.it

THE DIGITISATION OF THE BRIXEN'S HISTORIC CITY CENTER FOR THE HERITAGE EDUCATION

Francesca Condorelli, Alessandro Luigini*, Giuseppe Nicastro**

*Free University of Bozen, Faculty of Education – Bozen, Italy.

Abstract

This paper presents the experiences and outcomes of the EARTH_LAB laboratory at the Free University of Bolzano in the field of digitisation and enhancement of architectural and cultural heritage of South Tyrol. The work focuses on the research projects conducted by the group in the context of heritage education, with particular attention to the Alto Adige region. It describes the workflow used for the digitisation of architectures and the urban environment, including the use of technologies such as 3D laser scanning and photogrammetry. Additionally, it discusses the innovative approaches such as Neural Radiance Fields (NeRF) algorithms for 3D environment reconstruction, emphasizing the potential of this methodologies for generating rapid, cost-effective, and accurate reconstructions.

Keywords

Heritage Education, Virtual Reality, Augmented Reality, Serious games, Urban Heritage.

1. *Introduction*

This paper reports the experiences of the EARTH_LAB laboratory of the Free University of Bozen/Bolzano, which has been working for many years in the field of architectural representation and heritage digitisation with the aim of realising didactic paths for art education, both in schools and museums (Fig.1). This paper will present the research projects carried out by the group in the field of heritage education, with a focus on the historic centre of Brixen (Bz). The workflow used to digitise the investigated architectures and urban environment with the aim of developing interactive environments for heritage education and didactics will be presented.

Started in 2018, the project initiated an integrated digital survey campaign using state-of-the-art technologies such as 3D laser scanning, terrestrial and aerial photogrammetry (Fig 2). These methodologies were strategically used to document the city's most relevant architectural landmarks as well as a large portion of the urban environment related to the historic centre.

Alongside the technologies and methodologies now established in the field of digital documentation, innovative approaches such as Neural Radiance Fields (NeRF) algorithms were also chosen for the reconstruction of some 3D environments. The use of NeRF neural networks represents a state-of-the-art technique that refers to artificial intelligence algorithms used in the field of 3D modelling. Part of this study therefore focuses on utilising the potential of NeRFs to process panoramic (360-degree) images in order to generate fast, inexpensive and accurate 3D reconstructions to be used for the project purposes.

2. *Heritage education and digital languages*

Scientific literature and national and supranational legislation have long agreed that Cultural Heritage plays a crucial role, as an educational tool, in the development of human identity.

This implies that C.H. should not only be considered as a set of assets to be preserved and, if necessary, exhibited to the public, but also as a vehicle to transmit values and traditions to future generations. In this scenario, the use of digital technologies can only broaden the relevance of cultural heritage, fostering its accessibility more effectively and, consequently, its preservation and enhancement over time.

As has long been known, the hybridisation of traditional dissemination methodologies with the tools offered by contemporary digital languages

has therefore become an essential working asset for those working in the field of dissemination of tangible and intangible values and heritage (Luigini, Tramelli, Condorelli, Nicastro & Basso, 2023, Clini & Quattrini, 2021). We can therefore combine traditional dissemination methodologies with the tools offered by digital languages: the possible narratives are united by a common grammar (digital data), which, in its declination, gives rise to different prose. The nature of digital content, its being information matter whose language is a communicative form with only partially investigated potential and effectiveness, makes its experimentation central in those contexts related to promotion and enhancement such as, for example, museum didactics and heritage education (Mortara, Catalano, Belotti, Fiucci, Houry-Panchetti & Petridis, 2015; Paliokas, 2019; Luigini, Fanini, Basso & Basso, 2020).

The transmission of value is therefore configured as the transmission of knowledge and information that is decisive for the appropriation of the values of the cultural asset being valorised.

As already highlighted by research in the field of Education (Panciroli, 2021), the transmission of knowledge is not limited to the transmitter-receptor dualism alone, but we are now seeing a shift towards a more attentive, learner-centred approach: from this perspective, knowledge is generated by the experience of the active subject who acts in interaction with the social environment. At the same time, advances in neuroscience enable us to better understand the mechanisms of the brain that regulate perceptual interaction with our environment in order to explain the processes by which we acquire information: researches has shown how is fundamental the simultaneous connection between perception, action, emotion and cognition, because the world is not something that is given to us from the outside (transmitted and received without any significant contribution from the receiver of the message) but, on the contrary, we take part in it through the way we interact with the objects of our perception.

For these reasons, the concept of *mediatore* assumes particular importance in this perspective and we can define it both as the regulation of the distance between the cultural content to be transmitted and the subjects who are learning, but also as a form of representation of reality in which the reality being discussed is replaced with *simulati* in order to facilitate learning (Rivoltella, 2019). This *simulati* take the form of specific mediators active in the sphere of knowledge, which can be represented by people, objects and situations or contexts that fulfil different functions.

Fig. 1: A young user tries out some of the digital environments created by Earth_Lab.

In this field, we pay particular attention to those mediators that have developed with the advent of digital, defined as technological mediators, characterised by a strong multimedia component that makes it possible to integrate different languages in a single platform. Augmented Reality, for instance, represents an enhanced vision of reality thanks to the superimposition of virtual elements in a real scene: the real scene is thus amplified or enriched by the insertion of digital content that can manifest itself in animations, texts and videos that modify the pre-existing situation in order to enhance its

cognitive aspect (Macauda, 2018, Panciroli, Fabbri, Luigini, Macauda, Corazza & Russo, 2023).

The fruition of the contents takes place thanks to the mediating action operated by a device that acts as a veil between the real environment and the multimedia content: by framing a tag or a point of the scene appropriately arranged with the camera of one's own device, it is possible to display a digital content on the screen. By superimposing the information on the real scene, it expands the possibilities of reading it, at the same time allowing us to simultaneously observe both the object (as it is given to us in reality) and the critical readings and integrations (the digital content).

3D printing is a further important element of mediation: the possibilities offered by this technology do not only lie in the concept of a copy, a clone of the original work, but also in the possibility of activating a further sensory element represented by touch in the value transmission process. If augmented reality allows us to interpret information content through the sense of sight and, with the adoption of certain content, also the sense of hearing, 3D printing favours the transmission of information through the tactile component.

The possibility of creating faithful replicas of three-dimensional spaces and objects enables curators of cultural institutions (museums, libraries, archives, etc.), those responsible for the protection, preservation and enhancement of cultural heritage to enrich and expand collections and exhibitions with digital and virtual content, providing access to information according to both the user and the content, and the complexity of the information returned (Palma, Spallone & Vitali, 2018). Virtual reconstructions also make it possible to contextualise information about discrete objects, framing them in spatio-temporal frameworks that offer the possibility of diachronic readings of history (Puma, 2016).

Cultural places therefore become dynamic spaces, no longer just for collection and exhibition, but also for new forms of storytelling. This scenario prompts us to imagine new forms of interaction with cultural heritage that go beyond the traditional approach, in which information is communicated in a unidirectional way, and embrace the expressive potential of digital media that enable multiple exchange between user and object. Immersive digital environments offer experiences in which the user is placed at the centre of the same experience, as in the case of environments usable through visors.

These digital environments amplify interaction and immersion in cultural heritage, allowing the user to have a more engaging and meaningful experience.

Obviously, Virtual and Augmented Reality are far from new in the educational overview, and although everything about them is receiving enormous media attention and undergoing a complete paradigm shift without precedent (Beltran & Alvarado,2023), it is important to emphasise that even the newest and most promising technology has not emerged recently, especially when considered as an educational tool.

In fact, the first applications of virtual reality appeared in the late 1980s and, apart from a few unsuccessful experiments in the entertainment sector, as was to be expected, it was clear from the outset that its most promising applications would sooner or later be educational ones. Virtual reality is a powerful tool and not only in its immersive variants. In educational programmes, the critical issue concerns the natural entertainment capacity of virtual and augmented reality applications, which should warn against the danger of gamification that could easily turn such applications into a 'mere video game'.

Therefore, VR and AR must be carefully integrated into well-defined programmes with clear objectives and procedures (Pellas, Fotaris, Kazanidis & Welles, 2019).

3. Workflow and technologies employed

The workflow adopted by the group for the realisation of digital environments consists of three main phases: data acquisition, the subsequent data processing and the creation of 3D models to be used inside the applications. Each step is described in detail below.

The first step involved the acquisition of digital metric data of the historic city centre of Brixen/Bressanone with various campaigns for the architectural survey of monuments and urban heritage that saw the use of different technologies, including terrestrial laser scanning for the acquisition of point clouds, terrestrial and aerial SfM photogrammetry and panoramic photos taken with 360-degree cameras.

Once all operations related to the architectural survey campaigns were completed, in the second

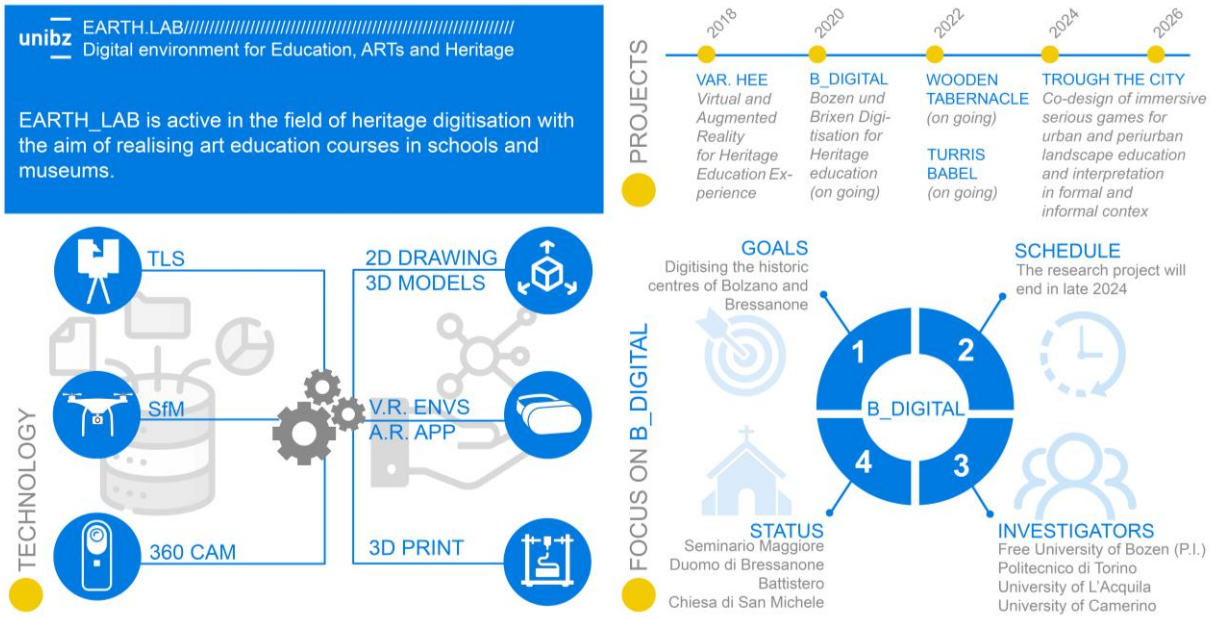

Fig. 2: Some of the research projects carried out by Earth_Lab in recent years. Below right is a summary of the B_Digital project structure.

phase of the project it was possible to proceed with the interpretation of the data and its subsequent processing, according to the planned restitution and use. Working with a workflow widely established in the field of integrated digital surveying, all the registration operations of the scans acquired with terrestrial laser scanner and SfM were carried out to obtain an optimal level of overlap between the different types of data and thus be able to proceed to the critical interpretation phases.

The third phase consisted in the production of navigable 3D models used for the construction of educational paths through VR and AR navigation dedicated mainly to the citizens and tourists of Brixen/Bressanone. The same models were subsequently used for the design and implementation of serious games for heritage education in schools. The employment of the acquired digital data in different applications (virtual tours, virtual or augmented reality applications) made it possible to design diversified user experiences able to meet the needs of a heterogeneous audience, while managing to contain costs and production times.

Traditionally, heritage documentation relied heavily on conventional methods such as photogrammetry and laser scanning. Photogrammetry utilizes photographs to construct precise 3D models, while laser scanning employs laser beams to capture intricate spatial data. Although these methods have been invaluable, they often demand substantial time, labor, and financial investments, rendering them less practical for extensive heritage projects.

In recent years, the advent of artificial intelligence (AI) has profoundly impacted 3D modeling in heritage environments. AI-driven algorithms, have risen in prominence due to their capacity to manage complex datasets and streamline the reconstruction process. Neural networks, in particular, have exhibited remarkable efficacy in generating intricate and lifelike 3D scenes. (Palestini, Meschini, Perticarini & Basso, 2024; Cabanes & Bonafè, 2021).

In this technology perspective NeRF, empowered by deep learning algorithms, presents a formidable means of reconstructing intricate 3D scenes. Neural Radiance Fields (NeRF) represent a revolutionary approach wherein a neural network is trained to generate and optimize a volumetric representation of a scene based on a set of source images. Initially devised for synthesizing new views of a scene, NeRF's volumetric representation can be converted into a 3D mesh, offering a compelling alternative to traditional photogrammetry for 3D scanning. NeRFs exhibit remarkable versatility in rendering challenging objects, including metallic, translucent, or transparent surfaces, as well as objects with intricate details. Furthermore, their adeptness in handling ambiguous observations, such as regions with homogeneous colors or repetitive texture patterns, positions them as promising solutions in

Fig. 3: The area of interest of the B_Digital project consists of the historical centre of the city of Bressanone (Bz): the main architectures investigated are to be found in the old part of the city.

heritage reconstruction (Condorelli, Rinaudo, Salvadore & Tagliaventi, 2021).

The forefront of research in digitizing cultural heritage, particularly through the integration of Neural Radiance Fields (NeRF) into interactive video game development, epitomizes a vibrant landscape where heritage preservation, education, and cutting-edge technology converge.

However, despite the immense potential of NeRF, obstacles remain. High computational demands present a significant barrier, constraining accessibility for researchers with limited computing resources. Additionally, there is more possibility of improvement in the resolution of the final point cloud generated by NeRF to ensure more faithful reconstructions of intricate details within cultural heritage settings. Current research endeavors are dedicated to refining NeRF methodologies to address computational challenges, enhance reconstruction quality, and optimize efficiency. This ongoing pursuit aims to unlock NeRF's full potential as a transformative tool in the digitisation and preservation of cultural heritage.

As mentioned above, a further methodology investigated by the research team relates to the possibility of creating 3D-printed prototypes of some of the architectures of the city of Brixen. One of the first elements investigated was therefore the choice of the most suitable printing technology for the purposes of the project: the choice, in this case, fell on the type of 3D printing that operates according to a Fused Deposition Modelling (FDM) process. Fdm printers base their operation on the use of a plastic filament (composed of thermoplastic polymeric material) which, once heated, is extruded from a nozzle and released onto a platform following a constrained movement pattern, which is useful for achieving the desired shape. The advantage of this printing technology, which is among the most popular in the consumer market, is probably due to its relative ease of use and costs that allow project budgets to be kept low.

4. The Earth_Lab's activities in the field of Heritage Education

Below are some of the results obtained by following the workflow just described.

4.1 The B_Digita projectl

The project B_Digital, - Bozen und Brixien Digitisation for Heritage education, envisages the digitisation of the most important architectural emergencies in the historical centres of Bolzano and Bressanone for documentation and enhancement purposes. The first phases of the project, started in 2020, had seen the working group engaged in an integrated digital survey campaign conducted on the most relevant religious architecture in the city of Brixen (Fig. 3, 4, 5). Initial data had been acquired on the Cathedral of Santa Maria Assunta and San Cassiano the city's main place of worship, and the nearby Church of San Michele.

Fig. 4: The B_Digital project: above, the data acquired for the Major Seminar, the first 2D outputs and the 3D printing test. Bottom, some views of the point cloud related to the scans acquired in the historical centre.

In this second phase, which began in September 2022, further data acquisition campaigns were conducted to integrate the results acquired in the previous months (Fig. 4).

Not far from the two churches is the Major Seminary, seat of the Theological Study of Brixen, and the adjoining library. The complex was surveyed in two phases: in October 2023, a Laser Scanner survey campaign was carried out with the Leica BLK instrument and approximately sixty colour scans were acquired of all the external fronts and elevations facing the inner courtyard, the church of the Holy Cross and, finally, some of the main rooms on the first floor, including the ancient library.

The L.S. acquisitions were integrated by a aerophotogrammetric survey campaign conducted with a Dji Mavic Mini 2 drone. All the data acquired were recorded and assembled in a unique point cloud, thus completing the dataset to be used in the subsequent recording phases.

Also as part of the B_Digital project, in December 2022, to coincide with the traditional Christmas market in Brixen/Bressanone, a photographic campaign was carried out using an Insta 360 camera, i.e. a digital camera capable of capturing high-resolution 360° panoramic photos: the panoramic images provide an immersive database (usable through visors and cardboards) necessary for the creation of serious games and virtual tours useful to tell the story of the territory and to convey, through the playful element, its value elements.

One of the project objectives relates to the report of 3D printed reproductions of some of the most important architectural landmarks in Brixen/Bressanone: in the last few months tests have therefore been conducted on the possibility of defining an effective and economically sustainable workflow for the creation of these replicas.

In November 2023, the first printing tests were conducted on the portion of the Seminario Maggiore relating to the main entrance: the printing tests were useful to define the most effective 3D modelling methods, the scale at which to print the 3D model as well as the quantity of plastic filament (PLA) required to create the final replica (Fig 4).

Next to the 3D replicas, the realisation of 2D outputs is still in progress: starting from the aerophotogrammetric shots taken, the ortho images were generated in colour and in high definition, which combined with the Point Cloud L.S., provide a detailed documental basis for the restitution of the main elevations of the building at a scale of 1:50. The drawings are still in progress.

Fig. 5: B_Digital project: the survey of the Brixen cathedral (views extracted from the point cloud).

4.2 The ancient library of the Seminario Maggiore

A notable highlight of this case study is the inclusion of the late-baroque library within the Major Seminary in Brixen. Erected in 1772, the library stands as a significant testament to the city's cultural heritage. Architecturally, it boasts a typical rococo rectangular layout, featuring a

Fig. 6: 360-degree panoramic image of the ancient library of the Seminario Maggiore.

double height and balconies on all four sides. The ceiling, adorned with frescoes by the renowned Austrian painter Franz Anton Zeiller, symbolizes the six theological disciplines. These frescoes originally dictated the thematic organization of the underlying books.

The project encountered a challenge in the 3D reconstruction of environments, particularly utilizing 360-degree videos captured with an Insta360 camera or a limited set of images (Fig. 6). In response, the researchers strategically opted for Nerfstudio as a suitable method for implementing Neural Radiance Fields (NeRF). This choice was informed by the capabilities of Nerfstudio, a library of modular components tailored for NeRF implementation, offering a versatile and effective solution (Martin-Brualla, Radwan, Saijadi, Barron, Dosovitskiy & Duckworth, 2022; Murtiyoso, Markiewicz, Karwel & Kot, 2023;).

The decision to focus on the 3D reconstruction of environments using 360-degree videos and images underscores a forward-looking approach to heritage digitisation (Barron, Mildenhall, Verbin, Srinivasa & Hedman, 2022). The application of NeRF through Nerfstudio serves as a pivotal component in achieving these objectives, showcasing the intersection of advanced technological tools and the preservation of cultural heritage (Llull, Baloian, Bustos, Kupczik, Sipiran & Baloian, 2023, Croce, Carotti, De Luca & Piemonte, 2023).

The methodology employed in the workflow for producing a high-quality NeRF model involves a process of scene capture, data preprocessing, and model training. Each step is designed to ensure optimal reconstruction quality of 3D scenes, particularly in the context of heritage digitisation.

The study successfully demonstrates the practical application of NeRF, particularly through Nerfstudio, in achieving precise 3D reconstructions of cultural heritage environments.

The results obtained (Fig. 7) show the feasibility and effectiveness of NeRF-based techniques in producing high-quality 3D models from a set of 360-degree images. These models have the potential to enhance heritage education

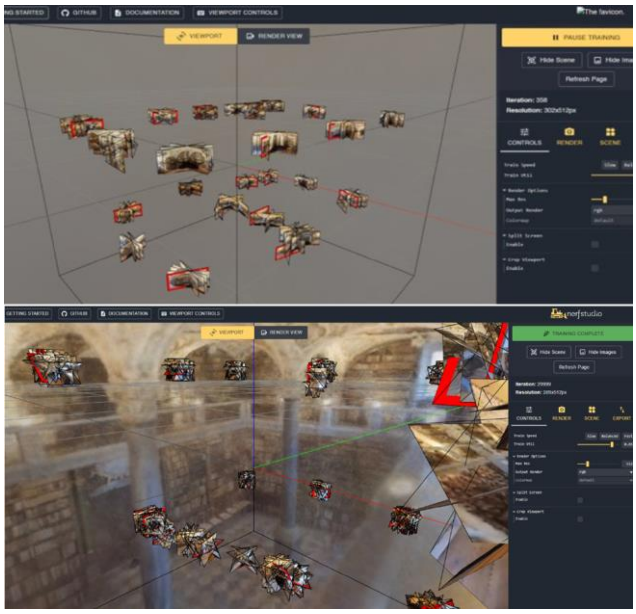

Fig. 7: NeRF processing of acquired panoramic images.

and elevate the visual fidelity of video game environments; at the same time, NeRF methodology offers notable challenges such as high computational requirements and resolution limitations that need to be addressed to maximize its impact in heritage preservation and education.

4.3 The Turris Babel project

Through the synergistic integration of pioneering technological methodologies and cross-disciplinary cooperation, our research endeavors to bridge the chasm between the annals of historical literature and the contemporary milieu, thereby facilitating the metamorphosis of Tourris Babel from a mere figment of imagination into a palpable reality accessible to all.

Utilizing state-of-the-art photogrammetric techniques and avant-garde 3D modeling methodologies (Borji,2022; Condorelli, Higuchi, Nasu, Rinaudo & Sugawara, 2022) we endeavor to transmute the depictions of Turris Babel into a tangible and traversable rendition (Fig. 8). The subsequent phase of our investigation is directed to crafting an augmented reality application, serving as a conduit through which the general populace can interact with and explore the three-dimensional representation, thereby widening accessibility to this fictional architectural marvel (Hammady, Ma & Powell, 218).

This effort not only addresses the problem of image acquisition in the absence of tangible references but also delves into the realm of artificial intelligence-driven algorithms to enrich the existing dataset (Borji, 2022; Ploennigs & Berger, 2022). The development of the augmented reality application not only amplifies the accessibility of our research but also provides a distinctive medium for immersive encounters and the dissemination of historical and architectural erudition to a diverse audience spectrum.

The portrayal of the Turris Babel within Athanasius Kircher's Archontologia occupies a distinctive and cryptic position within the realm of historical and architectural representations. Kircher's rendition of the Turris Babel, commonly known as the Tower of Babel, offers a window into the imaginative reconstruction of a structure that has long captivated scholarly intrigue and sparked fervent debate. Even today, Kircher's depiction of the Turris Babel continues to captivate scholarly minds and inspire artistic endeavors. It serves as a testament to the enduring fascination surrounding this iconic architectural wonder, serving as a nexus between ancient myths, historical inquiry, and creative imagination. Kircher's depiction of the Tower of Babel stands as a compelling artifact in the ongoing exploration of the intersection between art, history, and biblical narratives, underscoring its enduring significance.

Fig. 8: The Turris Babel project: the illustration from Kircher's work (top) and the project outputs.

This case study holds particular significance for several compelling reasons. Firstly, it pertains to an architectural structure that exists solely within the realm of imagination, yet holds

immense cultural and historical importance. Secondly, it serves as an iconic symbol, recognized across various cultures, making it easily identifiable and replicable through the application of advanced technologies, such as Artificial Intelligence. Thirdly, its presence within a somewhat limited literary work emphasizes the importance of devising methods for its broader dissemination, aligning with UNESCO's recommendations for the preservation and enhancement of tangible cultural heritage.

In the pursuit of creating an augmented reality (AR) application, a crucial requirement is the development of a 3D model depicting the Tower of Babel. Given the unique nature of this architectural marvel, the feasibility of utilizing photogrammetry to model such a structure is explored. Photogrammetry, a technique reliant on numerous images captured from various viewpoints, poses a significant challenge, particularly in scenarios where empirical references are lacking. Additionally, the extent of available data for 3D modeling is a critical aspect to consider.

To address these challenges, a comprehensive workflow is implemented. The initial phase involves acquiring images akin to the Tower of Babel, thereby expanding the image repository for photogrammetry through the utilization of AI-driven tools like Midjourney (Ho, Jain & Abbel, 2020; Rombach, BLattmann, Lorenz, Esser & Ommer, 2022). Subsequently, the model of the tower is constructed, leveraging AI-powered image retrieval and advanced photogrammetry techniques to enhance the 3D modeling process. Finally, an AR application is developed to allow the public to navigate and access the 3D model of the tower.

It is noteworthy that both the reconstruction of the tower and the development of the AR application were accomplished using cost-effective tools and open-source software, emphasizing accessibility and affordability in this innovative project.

The integration of AI-driven prompt-to-image systems, such as Midjourney, proves pivotal in generating novel tower images closely resembling the original illustration. By iteratively refining outcomes through various prompt settings, images essential for photogrammetric processing, particularly lateral views, are successfully recreated.

During the photogrammetric phase, specific points are identified to craft 3D models of the tower, drawing inspiration from Kircher's illustration. The resulting AR application seamlessly showcases a real-time, navigable tower model, enhancing user immersion through markerless technology. This interdisciplinary approach not only facilitates the visualization and dissemination of research to a wider audience but also promotes cultural preservation and understanding. AR and virtual reality (VR) apps serve as modern conduits, intertwining pedagogical knowledge with digital representation to foster active learning and comprehension of our cultural heritage. In essence, AR and VR apps offer a dynamic and enlightening pathway for exploring and cherishing the riches of our cultural heritage, bridging the gap between historical artifacts and contemporary audiences through engaging and interactive experiences.

4.4 The Var_HEER project

In the heritage enhancement and education paths implemented with content gamification, there is a testing phase on primary school children.

Fig. 9: The VAR_HEER project: scenes extracted from the designed digital environments and field testing (top) of immersive experiences.

Fig. 10: The Wooden Tabernacles project concerning the digitisation of some wooden tabernacles in the Abruzzo region: the project includes the realisation of a 1:5 scale 3D printed replica and an augmented reality APP.

For this reason, the serious games created in VR were tested by children between the ages of 5 and 12 (Fig. 9). In particular, the results of two different tests are reported. The first game was viewed through high-definition Oculus Rift VR HMD (head-mounted display) visors.

The second game was developed to be viewed by cardboard. In this case, this experimental serious game is based on the integrated use of 360° images to create the illusion of being in real space. Technically, the graphic quality is lower and the functionality simpler.

The educational results were excellent: children showed a lot of interest in VR games, both as a form of entertainment and as a new way of learning knowledge. The data showed that the cardboard-based game was more successful than the other, of lower graphical quality, because it was more intuitive and easier to use without external support, which is necessary when using VR on Oculus (Figure 4).

4.5 The Wooden Tabernacles project

The Wooden Tabernacles research project, which started in September 2022 and is still ongoing, concerns the digitisation of a series of wooden tabernacles made between the 17th and 18th centuries as historical-artistic evidence of the Capuchin order of Abruzzo (Del Vecchio, 2021).

The aim of the project is to obtain, by means of SfM photogrammetry, a series of geometrically accurate 3D models that can be used for the realisation of physical replicas of the surveyed objects using 3D printing (Marra, Vespasiano & Brusaporci, 2023). An Augmented Reality application will extend the user experience of the replica by adding a series of digital information layers (photos, videos, 3D models) that can be activated by framing the replica itself (Fig. 10). By combining this technology with 3D printing, it is therefore possible to associate a physical object

with a series of information contents that enrich its enjoyment.

Below are the results of the tabernacle of the Capuchin friars of Pescara of which the 3D prototyping and Augmented Reality application was realised, designed by implementing the Model Target functionalities available with the Vuforia libraries in the Unity software environment.

The print prototype proved adequate for the project's purposes, returning a physical reproduction of the object at a scale of 1:5, accurately reproducing the object's richness of detail.

The augmented reality platform was also extensively tested, demonstrating good results in terms of target recognition accuracy and thus correct overlap between the physical print and the object. Using the mapped 3D digital model, it was possible to superimpose the colour data of the real object onto the 3D print.

Finally, as far as the overall quality of the physical replica is concerned, the next steps of the project are to further increase its quality by working on the Layer High value (currently 0.15 mm) and to increase the printing time (currently 61 hours) in order to minimise the printing defects still present.

5. Conclusions

Digital applications prove to be useful tools for the transmission of cultural heritage value, as they are able to spread knowledge and new awareness through playful and accessible methods. The use of 3D models, V.R. and A.R. for the communication of cultural heritage offers the possibility of using the results of research in the field of Representation to create information layers that can enrich the experience of using these digital environments. Indeed, the 3D models generated do not only contain three-dimensional information such as measurements, geometries and textures, but also information on the historical phases of the site studied. This type of solution therefore allows data from different sources to be integrated in a simplified and intuitive way.

The final outputs of the different projects presented will be navigable and searchable in real time: this aspect is fundamental since it is a question of making information that is normally inaccessible available and experienceable in an active way. The virtual learning experience thus differs significantly from the classical learning experience and allows for greater user involvement.

REFERENCES

Barron, J. T., Mildenhall, B., Verbin, D., Srinivasan, P. P., & Hedman, P. (2022). Mip-nerf 360: Unbounded anti-aliased neural radiance fields. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 5470-5479.

Beltran Alvarado G.A. (2023). Augmented Reality (ar) in education, medicine and industry: a systematic review of literature. *Scires - SCIentific RESearch and Information Technology - Ricerca Scientifica e Tecnologie dell'Informazione*, *13*(1), 153-166.

Borji, A. (2022). How good are deep models in understanding the generated images? *arXiv preprint arXiv:2208.10760*.

Borji, A. (2022). Generated Faces in the Wild: Quantitative Comparison of Stable Diffusion, Midjourney and DALL-E 2. *arXiv:2210.00586*.

Cabanes, J. L., & Bonafé, C. (2021). Computer Vision algorithms performance in Architectural Heritage Multi-Image based projects. General overview and operative evaluation: the North Tower of Buñol´s Castle (Spain). *SCIRES-IT - SCIentific RESearch and Information Technology*, *11*(2), 125-138.

Clini, P., & Quattrini, R. (2021). Editorial. Digital Cultural Heritage, arts reproduction and museum systems. Languages and techniques in a Covid and post-covid scenario for new forms of heritage against the silence of a fragile culture. *SCIRES-IT - SCIentific RESearch and Information Technology, 11*(1), 1-10.

Condorelli, F., Rinaudo, F., Salvadore, F., & Tagliaventi, S., (2021). A comparison between 3D reconstruction using NeRF neural networks and MVS algorithms on cultural heritage images. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 43(B2-2021),* 565–570.

Condorelli, F., Higuchi, R., Nasu, S., Rinaudo, F., & Sugawara, H. (2019). Improving performance of feature extraction in SfM algorithms for 3D sparse point cloud. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *XLII-2/W17*, 101–106.

Croce, V., Caroti, G., Luca, L. De, & Piemonte, A. (2023). Neural radiance fields (NeRF): review and potential applications to digital cultural heritage. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-M-2-2023*, 453–460.

Del Vecchio L. (2001). *Fratelli Marangoni e tabernacoli lignei. Un capitolo di storia cappuccina in Abruzzo*. Lanciano (Ch): Edizioni Tabula.

Hammady, R., Ma, M., Powell, A., 2018: User Experience of Markerless Augmented Reality Applications in Cultural Heritage Museums: 'MuseumEye' as a Case Study. In L. De Paolis & P. Bourdot (Eds), *Augmented Reality, Virtual Reality, and Computer Graphics. AVR 2018. Lecture Notes in Computer Science, vol 10851* (pp. 349-369), Cham: Springer.

Ho, J., Jain, A., & Abbeel, P.(2020). Denoising diffusion probabilistic models. In *Proceedings of the 34th International Conference on Neural Information Processing Systems* (pp. 6840-6851).

Llull, C., Baloian, N., Bustos, B., Kupczik, K., Sipiran, I., Baloian; A. (2023). Evaluation of 3D Reconstruction for Cultural Heritage Applications. In *Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV) Workshops* (pp. 1642-1651).

Luigini, A., Tramelli, B., Condorelli, F., Nicastro, G., & Basso, A. (2023). Tre esperienze di imagin(g) per il patrimonio = Three experiences of imagin(g) heritage. In *IMG23: Atti Del IV Convegno Internazionale e Interdisciplinare Su Immagini e Immaginazione = Proceedings of 4th International and Interdisciplinary Conference on Images and Imagination* (pp. 490–497).

Luigini, A., Fanini, B., Basso, A. & Basso, D. (2020). Heritage education through serious games. A web-based proposal for primary schools to cope with distance learning. *VITRUVIO International Journal of Architectural Technology and Sustainability*, *5(2)*, 72–85.

Macauda, A. (2018). *Arte e innovazione tecnologica per una didattica immersiva*. Milano: Franco Angeli.

Marra, A., Vespasiano, L. & Brusaporci, S. (2023). Digital and Physical Replicas for the Study and Valorisation of Archaeological Artefacts: the Lead Seal of Pope Gregory Ix from the Archaeological Excavation at Amiternum (Aq). *Scires - SCIentific RESearch and Information Technology - Ricerca Scientifica e Tecnologie dell'Informazione*, 13(2), 61-70.

Martin-Brualla, R., Radwan, N., Sajjadi, M. S. M., Barron, J. T., Dosovitskiy, A., & Duckworth, D. (2021). NeRF in the Wild: Neural Radiance Fields for Unconstrained Photo Collections. In *Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition* (pp. 7206–7215).

Mortara, M., Catalano, C.E., Bellotti, F., Fiucci, G., Houry-Panchetti, M. & Petridis, P. (2015). Learning cultural heritage by serious games. *Journal of Cultural Heritage, 15(3)*, 318–325.

Murtiyoso, A., Markiewicz, J., Karwel, A. K., & Kot, P. (2023). Investigation on the use of NeRF for heritage 3D dense reconstruction for interior spaces. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XLVIII-1/W3-2023, 115–121.

Palestini, C., Meschini, A., Perticarini, M. & Basso, A. (2024). Neural Networks as an Alternative to Photogrammetry. Using Instant NeRF and Volumetric Rendering. In A. Giordano, M. Russo, R. Spallone (Eds), *Beyond Digital Representation. Digital Innovations in Architecture, Engineering and Construction* (pp. 471-482). Cham: Springer.

Paliokas, I. (2019). Serious games classification for digital heritage. *International Journal of Computational Methods in Heritage Science (IJCMHS) 3(2)*, 58–72.

Palma, V., Spallone, R. & Vitali, M. (2018). Digital Interactive Baroque Atria in Turin: A Project Aimed to Sharing and Enhancing Cultural Heritage. In A. Luigini (Ed.), *Proceedings of the 1st International and Interdisciplinary Conference on Digital Environments for Education, Arts and Heritage. EARTH 2018* (pp. 314-325). Cham: Springer.

Panciroli, C., Fabbri, M., Luigini, A., Macauda, A., Corazza, L. & Russo, V. (2023). Augmented Reality in Arts Education. In A.Y.C. Nee, S.K. Ong,(Eds), *Springer Handbook of Augmented Reality* (pp. 305-333). Cham: Springer.

Panciroli, C. (2021). Conoscenza e apprendimento. In C. Panciroli (Ed.), *Elementi di didattica post-digitale* (pp. 22-25). Bologna: Bononia University press.

Pellas, N., Fotaris, P., Kazanidis, I. & Wells, D. (2019). Augmenting the learning experience in primary and secondary school education: a systematic review of recent trends in augmented reality gamebased learning. *Virtual Reality, 23*, 329–346.

Ploennigs, J., Berger, M. (2022). AI Art in Architecture, Artificial Intelligence. *arXiv:2212.09399*.

Puma P. (2016). The digital cultural heritage- Digitch programme: experiences of documentation and survey for the smart fruition of archaeological heritage. *Scires - SCIentific RESearch and Information Technology - Ricerca Scientifica e Tecnologie dell'Informazione*, *6* (1), 151-164.

Rivoltella, P. C. & Rossi, P. G. (2019). *Tecnologie per l'educazione*. Milano: Pearson Italia.

Rombach, R., Blattmann, A., Lorenz, D., Esser, P., & Ommer, B. (2022). High-resolution image synthesis with latent diffusion models. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition* (pp. 10684-10695).