VIRTUAL ARCHAEOLOGY

ENHANCING ACCESSIBILITY TO CULTURAL HERITAGE THROUGH DIGITAL CONTENT AND VIRTUAL REALITY: A CASE STUDY OF THE SARMIZEGETUSA REGIA UNESCO SITE

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Abstract: The process of documenting cultural heritage digitally has emerged with the recent technological developments. One of the direct consequences of using digital devices to promote cultural heritage is to educate the end-users and to exceed their initial expectations regarding their interaction and engagement with cultural heritage assets. Creativity is encour-aged and stimulated by technology; as a result, cultural heritage domain must use technologies and tools from various domains such as engineering (3D scanning), gaming industry (VR headsets), digital marketing (interactive screens) to create interactive exhibitions. These tools can be paired with classical cultural heritage exhibition methods to attract, engage and support end-users more efficiently and effectively by creating unprecedented interactive. For this endeavor more than 560 artifacts have been digitized, the monuments and the fortress have been digitally reconstructed and integrated in digital applications that were combined with classical museum exhibition methods. By doing so, the paper also brings contributions concerning the methodologies used for deploying state of the art scanning and digitizing technologies. The main motivation was to bring classic exhibition techniques to modern times and to attract the young audiences to museums, thus identifying how they can be more engaged, involved and educated within the mixed museum spaces.

Keywords: *virtual reality; cultural heritage; 3D scanning; digital reconstruction; Unity; museum exhibition, interactive applications.*

1. INTRODUCTION

Virtual reality has become the most popular medium used for recreating and re-enacting past cultures[1]. This is mostly because virtual reality has become one of the most promising technologies (along with Augmented Reality) that alters the ways that we, as humans experience and interact with cultural heritage assets. These modern digital technologies have produced remarkable difference regarding the way the general public is currently experiencing and interacting with cultural heritage either directly in their homes, or at museums and in situ. The most important assets for immersive digital applications are 3D models, and over the past decades it has become

[1] MACHIDON/DUGULEANA/CARROZZINO 2018.

very common to use 3D digitization and 3D modeling for this purpose[2]. As presented by other researchers[3], the vast majority of people are familiar with the term virtual reality, but they are unsure about the potential uses of this technology.

With the development of 3D reconstruction software and virtual reality systems, most celebrated places from the world have been rebuild and integrated in various virtual reality environments[4]. Around the world, these virtual reality systems have started to appear in various museums and galleries. The vast availably of high-speed internet connections[5] and the wide availability of commercial virtual reality headsets[6] have helped the rapid adoption of these technologies to support cultural heritage promotion.

Throughout history, both human conflicts[7] and natural disasters[8] have destroyed our global heritage. In the case of the Dacian capital, Sarmizegetusa Regia, the fortress was partly dismantled by the end of the First Dacian war (102 AD) when the fortress was invaded by the Roman Empire, led by Emperor Trajan. The fortress was rebuild after the First Dacian War, but after the Dacians have been defeated during the Second Dacian War (106 AD) the Romans have systematically destroyed the fortress, its fortification, temples, buildings and have started to deport inhabitants[9].

This paper aims to provide useful contributions regarding the use of 3D scanning technologies and techniques to obtain accurate digital documentation regarding the terrain of the sacred area from Sarmizegetusa Regia archaeological site, as well as the position of each known sanctuary from this area. The virtual reality environment used to disseminate the results makes use of this accurate 3D data and it is paired with 3D scanned artifacts belonging to the Dacian Civilization from Orăștiei Mountains to define an accurate virtual reality experience allowing users to explore, learn and interact with digital assets. Within the paper there are also presented various digital applications that make use of tracking sensors to create interactive digital experiences within museums exhibitions.

In the following section, the authors describe the historical background of Sarmizegetusa Regia archeological site starting with the large-scale systematical destruction process initiated by the Romans after they defeated the Dacians, during the Second Dacian War, up to the present conservation status of the Dacian Fortresses of the Orăștiei Mountains that has been included in the UNESCO World Heritage list in 1999[10].

2. SARMIZEGETUSA REGIA ARCHAEOLOGICAL SITE BACKGROUND

Sarmizegetusa Regia was an important political, military and religious center that has made its influence felt at certain times over the entire Dacia. The settlement dated from the 1st century AD – beginning of the 2nd century AD and it was probably the residence of the kings who succeeded Burebista[11]. The end of the settlement was violent, according to the archaeological data available today, after the Romans conquered the settlement, the Romans have stayed within the region to prevent Dacians from returning to their former capital, and then few years after, the settlement was completely abandoned and gradually forgotten. The settlement was rediscovered at the beginning of the 19th. Since 1999, under the name of Dacian Fortresses of the Orăștiei Mountains, the site of Sarmizegetusa Regia, along with five other fortifications from the defensive system of the capital of the Dacian Kingdom, have been included in the UNESCO World Heritage list[12].

The settlement was positioned on the slopes of Grădiștii Hills, in the Orăștiei Mountains and had a length (on the main axis) of about 4.5 km and according to the archaeological observation, there was no previous dwelling[13]. As a result, the chosen area gave the settlement the advantage of not having the inherent constraints in the case of successive dwellings, but at the same time, it also meant a major constructive effort. The major constructive effort involved the process of terracing the mountain slopes, according to the archaeologists there are currently mapped over 260 anthropogenic terraces[14]. Some of them have only several square meters while others have considerable areas (reaching up to about one hectare); these large terraces are supported by massive stone walls. The placement of terraces, the systematization of the dwelling, the fortification, the visible monumental architecture especially in the case of the temples illustrate a coherent urban approach, most likely under the sign of the royal authority.

The systematic archaeological research carried out for almost a century at the site of Sarmizegetusa has revealed a settlement composed of three distinct parts. The *fortification* raised around a plateau with an altitude of 1000 m, *the sanctuary*[15] positioned in the immediate vicinity and *the civil settlement*[16] around and within the civil settlement there were multiple workshops with various crafts, a blacksmith shop within this area was digitally reconstructed using 3D scanned iron staples, hinges and other metallic artifacts[17]. The constructions in the capital was mainly from stone and wood, their state of conservation varying greatly. Thus, the walls created with limestone blocks according to a Hellenistic influence technique known as *Murus Dacicus, which consisted of two outer walls made out of stone blocks filled with gravel,* and rocks cemented together with clay and compacted. The structure uniqueness was the scorched wood tie beams that connected the two outer walls with a dovetail joint located at the upper surface of the stone blocks[18].

The status quo of the archaeological site is illustrated in Figure 1. The photograph is focused on the large round temple and the paved road that links the fortification walls

2 EL-HAKIM *et alii* 2004.
3 CIRULIS/PAOLIS/TUTBERIDZE 2015.
4 YOUNES *et alii* 2017.
5 ZIKRIA *et alii* 2018.
6 TUSSYADIAH *et alii* 2018.
7 GROIZARD/SANTANA-GALLEGO 2018.
8 MARRION 2016.
9 ROSSI 1971.
10 ANON n.d.
11 GLODARIU 1996.
12 ANON n.d.; BÂRCĂ 2019; BÂRCĂ 2019a; NEAMȚU/BÂRCĂ/BUNA 2020.
13 GLODARIU 1996.
14 FLOREA 2017.
15 MATEESCU 2012.
16 DAICOVICIU/FERENCZI/GLODARIU 1989.
17 COMES/BUNA/BADIU 2014.
18 SERRAVALLE *et alii* 2019.

Fig. 1. Sarmizegetusa Regia (ANON n.d.): (**a**) The fortification wall created with limestone blocks, above the white mark is the reconstructed wall and underneath the remaining structure of the initial wall; (**b**) The large round temple with some of the initial plinths as well as reconstructed plinths, the photograph has been taken from the entrance point of view of the temple.

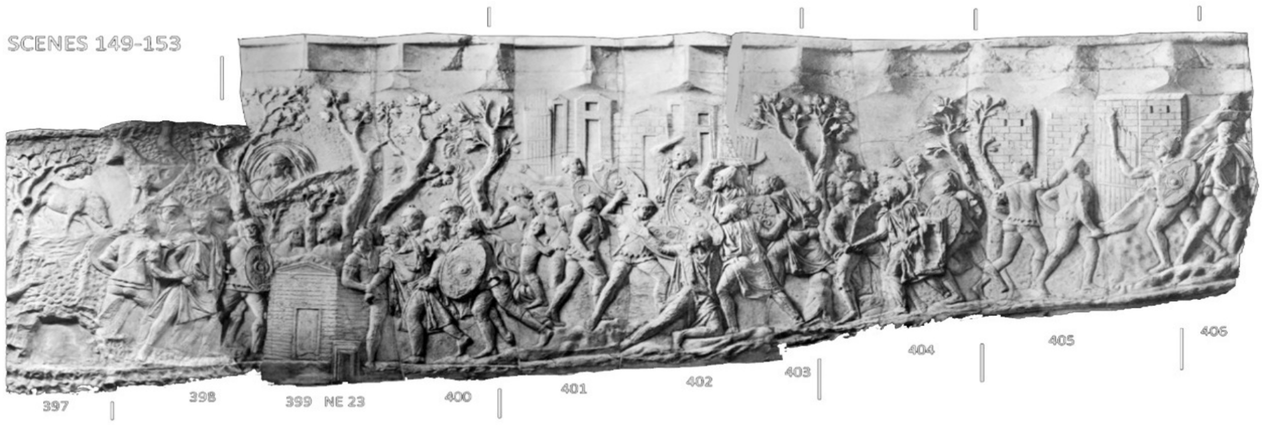

Fig. 2. Scenes 149-153 from the Column of Trajan illustrating the aftermath of the Dacian Wars (ANON n.d.).

with the sacred area, which contains multiple temples of various size and geometrical shapes.

Some monuments are preserved well enough, so that visitors can understand without too much difficulty how the respective buildings looked in antiquity, what was their utility, the particularities of the construction etc. For other monuments, the constructions were strongly affected most likely during the conquest of Sarmizegetusa by the Romans; therefore, for the public today it is more difficult to imagine their appearance and purpose. Particular elements of the settlement have been observed from an archaeological point of view in terms of the civil architecture. Among them being complex houses plans (buildings with several rooms, sometimes floors) and the use of construction materials that in some cases rarely are attested for the rest of Dacia (limestone and andesite for the foundation of the buildings, glass and lead for windows).

Sarmizegetusa Regia is one of the most important ancient sites from the territory of Romania. Sarmizegetusa Regia along with the other Dacian fortresses from the Orăștiei Mountains have lately become one of the most important tourist attractions of Transylvania. The number of people who arrive annually to Grădiștea de Munte has increased significantly in recent years (from 34,346 tourists in 2014 to 77,250 in 2019). It is important to state the fact that the number of tourists could only be counted after the moment in which the local council of Hunedoara took the archaeological site in its administration in 2012[19].

The only visual references regarding Sarmizegetusa Regia fortress are present on the Column of Trajan[20]. The commemorative Column that was funded by the rich, spoils Trajan brought to Rome as booty from the Dacian Wars illustrates the two separate campaigns over the years 101-102 AD and 105-106 AD regarding the Roman-Dacian war. The final scene illustrates the conclusion of the war in Dacia; this section illustrates the Romans torching Dacian buildings (Fig. 2), taking prisoners and the expulsion of the Dacians from Sarmizegetusa Regia fortress.

Because of the reasons mentioned above, the digital reconstruction of the Dacian capital of Sarmizegetusa is important, to ensure the promotion and preservation of this great capital belonging to the world global heritage.

This paper aims to be a useful contribution to the process of recreating past cultures virtual reality experiences, by using state of the art virtual reality technologies to recreate the Sarmizegetusa Regia sacred area. Its purpose is

[19] BÂRCĂ 2019; BÂRCĂ 2019a; NEAMȚU/BÂRCĂ/BUNA 2020.
[20] ANON n.d.

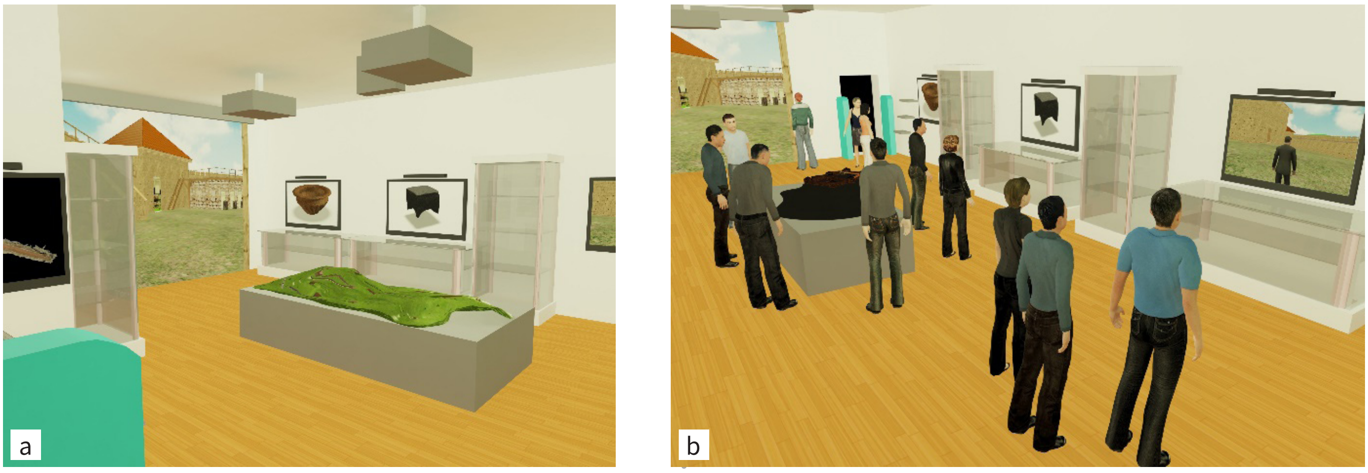

Fig. 3. The initial proposed 3D sketches of the two museum exhibitions: (**a**) The exhibition room features multiple projector, natural tracking sensors, as well as museum secured exhibition shelves so that visitors can see the artifacts in real life and interact digitally with them; (**b**) One of the exhibition room filled with visitors that are interacting with the digital applications controlled by tracking sensors (Microsoft Kinect).

to integrate 3D models obtained using accurate 3D scanners (terrestrial and handheld scanners) to define accurate 3D representation of the fortress with its sanctuaries and artifacts that belonged to the Dacian civilization that inhabited the fortress.

The research follows the current trend of applying modern technologies to recreate past civilizations, most of the world`s best known places have been digitally remodeled and reconstructed with the help of computer aided design (CAD) and digital content creation (DCC) software supported by 3D accurate in situ documentation.

3. OBJECTIVES AND MOTIVATION

The main objective of this paper is to highlight the advantages of integrating 3D scanning (terrestrial laser scanning, laser scanning, structured light scanning) techniques to generate detailed content suited for various digital applications and virtual reality environments.

The initial motivation was the precise documentation of the Sarmizegetusa Regia archaeological site, specially the sacred area with the exact placement of each sanctuary's remaining limestone and pillars. Other researchers such as Yastikli[21] worked on digital documentation of cultural heritage with both laser scanning and digital photogrammetry techniques. His research highlights the fact that the precise documentation of cultural heritage assets is essential to ensure its protection and having digital documentation improves scientific studies carried out during the creation of 3D reconstructed models, as well as during the restoration and renovation process.

Multiple motives support the 3D digital documentation, digital reconstruction and virtual reality dissemination of archaeological site such as:

- Documenting the terrace and the historical building's limestone remaining to ensure the accurate reconstruction in case of natural disasters such as (flood, erosion, earthquake, fire, etc.);
- Providing online databases based on Europeana APIs (Application Programming Interfaces[22] with interactive 3D models, metadata, audio and video files, to support virtual tourism and encourage people to visit both the archaeological site and the museums exhibitions;
- As presented in[23] innovative museums exhibitions manage to attract more visitors and keep them more engaged thus stimulating interactive learning;
- The possibility to visualize the archaeological site from multiple point of views, some that are impossible in the real world due to their positioning and accessibility;
- Defining digital educational materials that can be used both by students, researchers and visitors[24];
- Creating interactive virtual reality applications based on gamification[25] to attract a larger public formed from both children, students and adults to interact with cultural heritage assets;
- The use of tracking sensors to capture natural gestures[26] to provide visitors interaction within the digital museum exhibitions.

With the proposed objectives and motivation target defined, the research team started with the 3D digital documentation of both the archaeological site using terrestrial laser scanners and drones. As well as working at digitizing the inventory regarding the Dacian civilization of the Orăștiei Mountains from the National Museum of Transylvanian History in Cluj-Napoca and Museum of Dacian and Roman Civilization from Deva using handheld laser scanners and structured light scanners.

4. MATERIALS AND METHODS

The first step taken to start the preparation of the two mixed real/virtual exhibitions from the two partnered museums was to setup an interdisciplinary team that included historians, archaeologists, museographers, engineers and programmers who offered the required abilities, skills and knowledge. With the team assembled, the six proposed exhibitions have been sketched out; their main purpose was to capitalize on the movable and immovable

[21] YASTIKLI 2007.
[22] FREIRE *et alii* 2018.
[23] CARROZZINO/BERGAMASCO 2010; HASHIM/TAIB/ALIAS 2014; PALLUD 2017.
[24] NEAMȚU *et alii* 2012.
[25] DAMIANO *et alii* 2016; FARAZIS *et alii* 2019.
[26] KYRIAKOU/HERMON 2019.

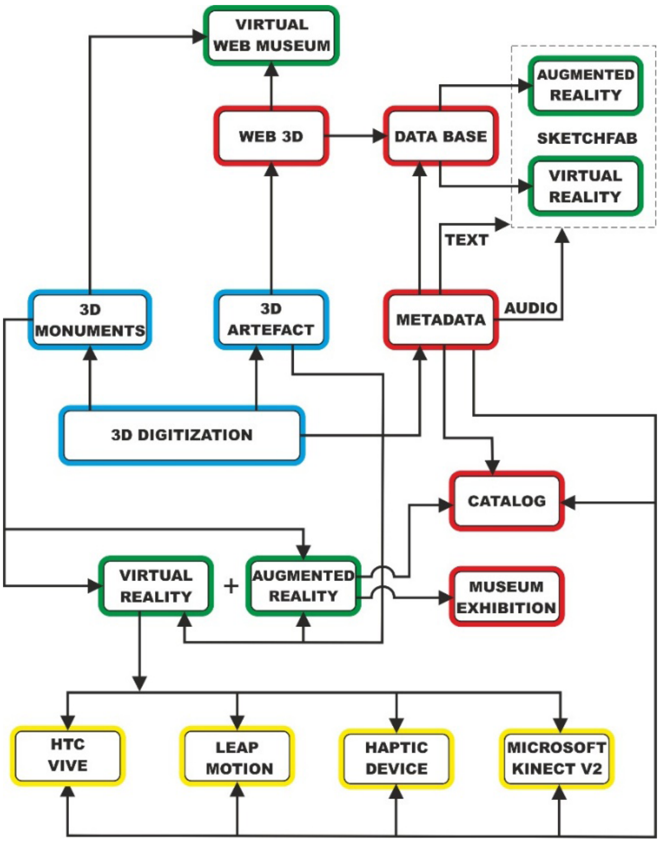

Fig. 4. The work methodology used to capitalize on the 3D digitization of Dacian cultural heritage assets by creating interactive digital applications for the thematic museum exhibitions.

cultural heritage assets that have a direct connection with the Dacian civilization from the Orăștiei Mountains.

The chosen theme was generic and initially it was intended to present the ancient daily life through thematic exhibitions that will focus on various aspects such as crafts, adornment, jewelry, tools, weapons, etc. The initial exhibition plans were also roughly sketched in 3D (Fig. 3) considering the exhibition room sizes available within the museums and the estimated costs of the equipment that could be integrated within the two museums exhibition areas.

The following categories were defined in order to create the thematic exhibition events within the museums and to offer visitors the initiative to return to the exhibition once the thematic exhibition are changed:

- The diet
- Domestic activities
- Crafts
- Agriculture
- Trade
- Weaponry
- Art, identity and imaginary
- Dwellings
- Water storage and supply installations
- Religious Architecture
- Aspects of the military architecture

For each category, on average, 40 representative artifacts were prepared to be part of the thematic exhibitions. Based on the connections between the artifacts, the locations of their discovery, and the buildings/monuments, which they were linked. The digital applications were defined based on these categories to put the artifacts in context. During this process, some of the fragmented artifacts were digitally restored.

In the second stage, the digitization of historical artifacts and monuments was started. The work plan is presented in Figure 4.

The 3D digitization equipment used within the digitization process is presented in Figure 5. The artifacts that are linked with the Dacian civilization from the Orăștiei Mountains were digitized using a wide variety of handheld 3D scanners. Aspects during the 3D scanning of a limestone hemisphere is presented in Figure 6a. The high

Fig. 5. The equipment used for the 3D digitization of both large-scale terrain with its terraces and monuments as well as the artifacts from the two museums inventories.

Fig. 6. Aspects during the digitization process: (**a**) The 3D scanning of a limestone hemisphere using a structured light scanner; (**b**) The 3D scanning of the Sarmizegetusa Regia Sacred area, using a terrestrial laser scanner.

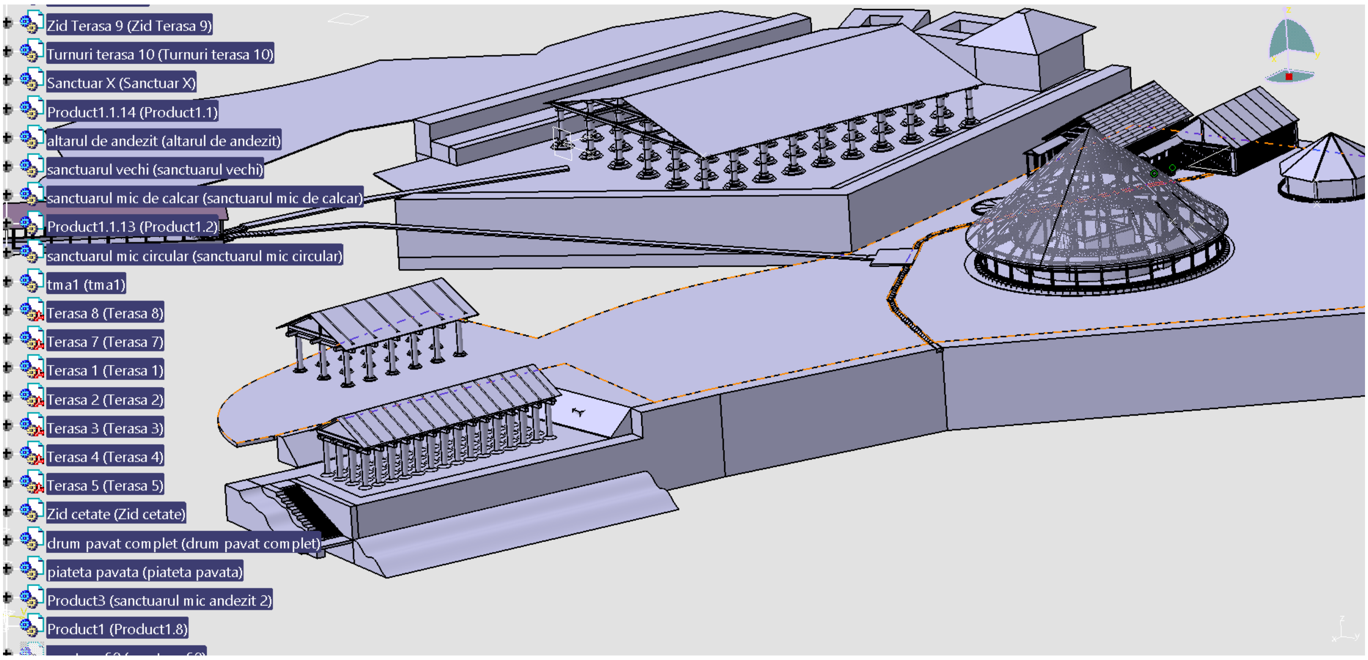

Fig. 7. The first step of the 3D reconstruction process of the wall and monuments from Sarmizegetusa Regia was to define the geometry of the buildings, walls and terraces.

precision terrestrial laser scanner (Fig. 6b)[27] and the two UAV drones that were used to gather the 3D registration and documentation of the terrain with its terraces and monuments are illustrated in Figure 6.

After the artifacts have been 3D scanned, the resulting meshes were processed to obtain a wide variety of optimized 3D models that can be used in various types of AR, VR or web-based applications.

The digital restoration of the monuments was started with the 3D scanning of the monuments and was done in two stages. The first step involved the 3D modelling in a CAD software (Computer Aided Design) using CATIA V5 solution (Fig. 7), the second step involved adding fine details and texturing in 3ds Max from where they were exported in various formats for AR and VR applications. The workflow has been disseminated in detail by the authors in a related research article[28].

The initially 3D reconstructed geometry from CATIA V5 was exported to 3ds Max along with the point cloud reference generated by the terrestrial scanner and within 3ds Max the 3D models were added fine details both as 3D models and high-resolution UV Mapping textures, this step is presented in Figure 8.

In parallel with 3D modeling, the metadata of each digitized artifacts and monument was organized according to the Europeana scheme to ensure the project database compatibility with Europeana platform[29]. The project database follows the requirements of the Europeana Data Model (EDM), which offers major improvements on ESE model, which was the initial Europeana data model by enabling data enrichment from a range of selected authoritative sources.

[27] ANON n.d.

[28] BUNA *et alii* 2014; COMES *et alii* 2017; NEAMȚU/BÂRCĂ/BUNA 2020.

[29] ANON n.d.

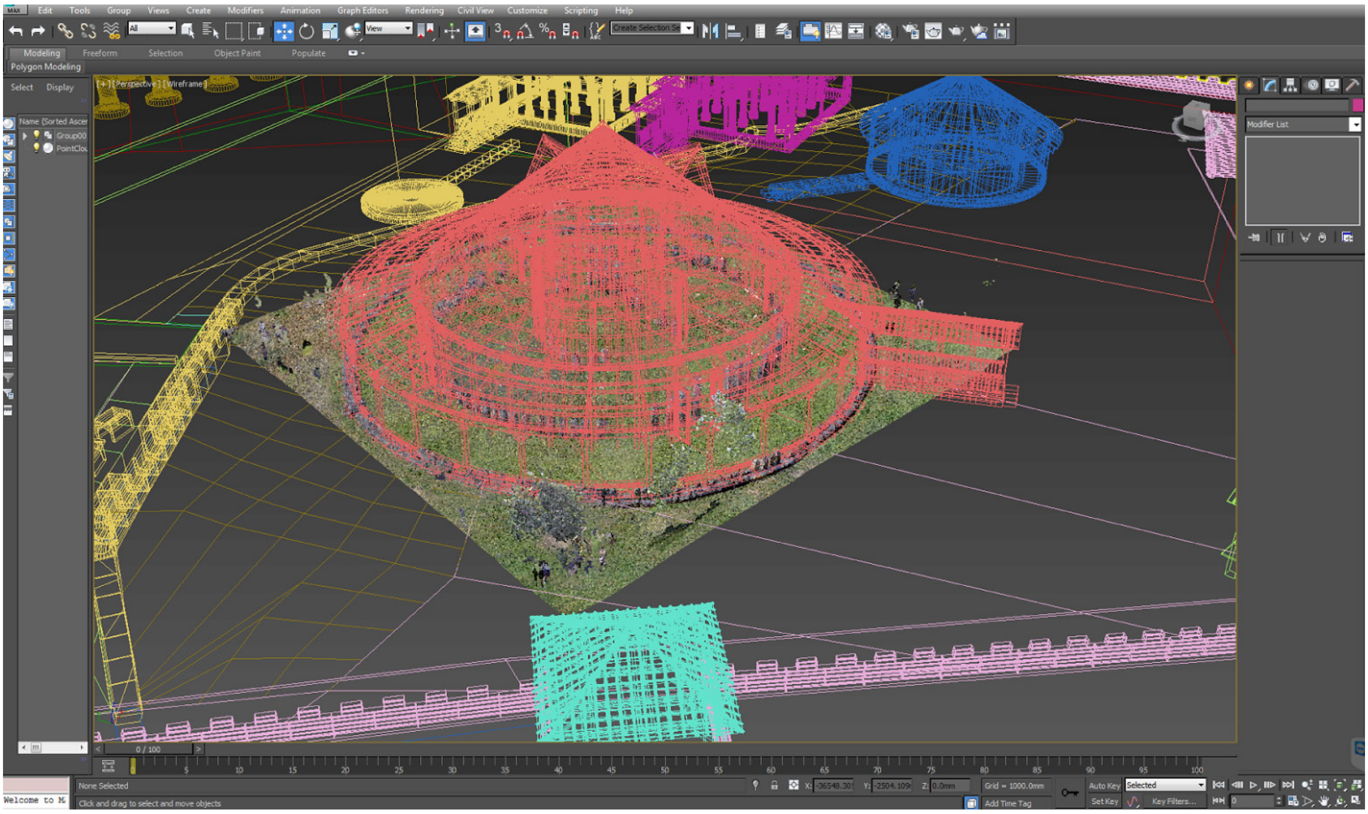

Fig. 8. Adding 3D details to the buildings and high-resolution textures within 3ds Max

Fig. 9. Some of the hardware equipment used for the digital applications, starting with tracking sensors, haptic devices, and various head mounted displays suited for virtual reality applications.

Having the 3D documentation process started and multiple 3D models uploaded to the online database[30], the mixed research team started to work on the next step, which involved the development of digital applications on a wide variety of devices (Fig. 9), aimed at creating innovative cultural heritage museum exhibitions.

5. DIGITAL APPLICATIONS OVERVIEW

During this project, the mixed research team has developed a plan to capitalize on the cultural heritage represented by the Dacian Civilization from the Orăștiei Mountains. The plan was based on the following digital cultural heritage vectors: online promotion using interactive 3D models, through interactive exhibitions, using interactive printed materials and through some demonstrations that involved digital equipment and applications hosted directly on the Sarmizegetusa Regia archaeological site.

[30] ANON n.d.

5.1. Online Web Database

The simplest method of interaction with the digital cultural heritage assets of the Dacian Civilization from the Orăștiei Mountains is through a web-based database. The online database's main advantage[31] is that it can be accessed worldwide (Fig. 10), therefore it offers the highest exposure, but the drawback is the interaction methods of the users are limited to visualizing the 3D artifacts and monuments on the screen, having the possibility to scale and rotate the models.

The digitized artifacts were organized into the online database, which currently contains over 560 artifacts, each with a complete set of metadata. They were also indexed in Europeana, the largest aggregator of digital cultural heritage in the world, where Technical University of Cluj-Napoca[32] is the fifth largest provider of 3D content. For each 3D model,

[31] ANON n.d.
[32] ANON n.d.

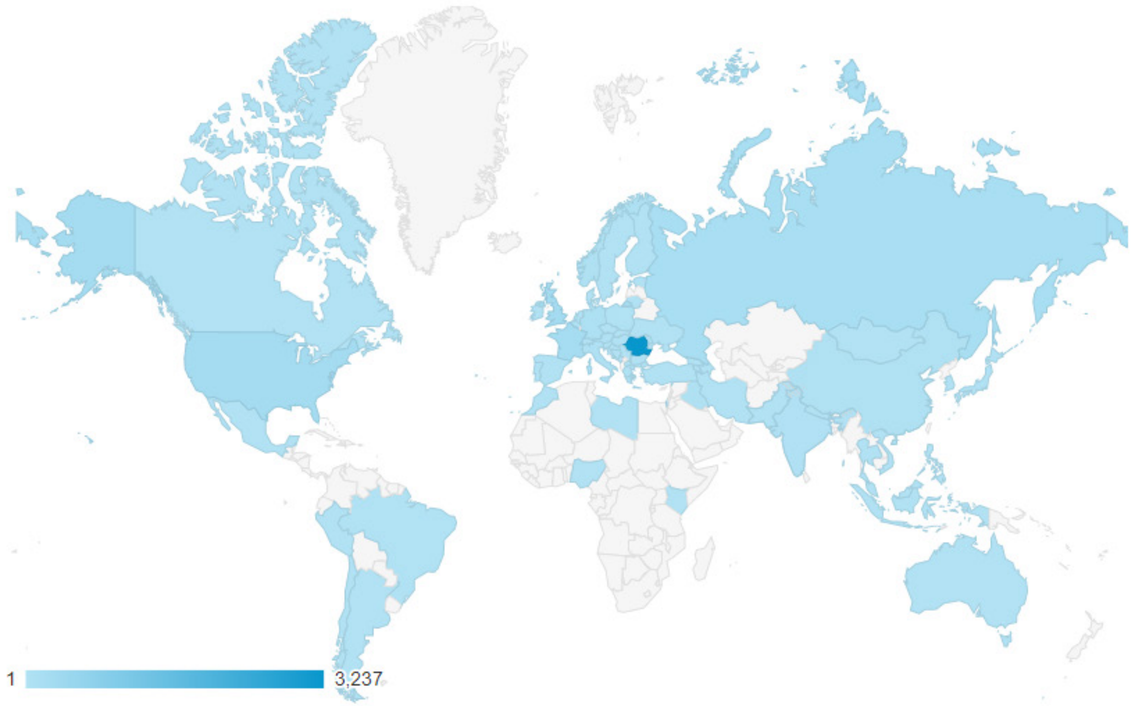

Fig. 10. Countries from which the database was accessed.

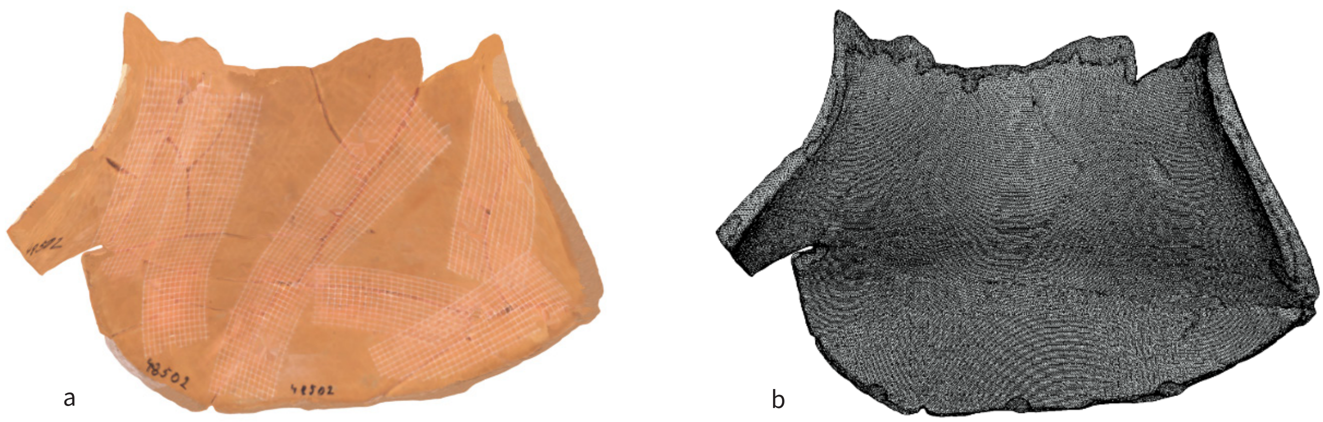

Fig. 11. The quality of the 3D digitization: (**a**) Textured view of a fragmented ceramic vessel, the ID number of the artifact can be spotted on the surface of the model in high detail; (**b**) 3D mesh view of the fragmented ceramic vessel.

3D PDF files were created that can be downloaded and used in various activities, a processed version of the models was uploaded to the 3D content sharing platform Sketchfab were each partnered Museum has an individual account and the 3D models are also embedded within the database[33] (Fig. 11). On the Sketchfab[34] platform the artifacts can be stereoscopically visualized with a smartphone and virtual reality head mounted display, even a card board one, the models are also accompanied by an audio file, with explanations in English.

To create more web-based interactions for the users, a virtual web-based tour was developed. The tour integrates a series of 3D reconstructed buildings and artifacts. The users can navigate the scene using the keyboard and the mouse, the application makes use of gamification elements (Fig. 12) allowing users to navigate dynamically the virtual environment. In various places, hot spots are defined

Fig. 12. Virtual web-based applications that makes use of gamification elements to present various aspects regarding the Dacian Civilization from Orăștiei Mountains buildings and artifacts.

[33] ANON n.d.
[34] ANON n.d.

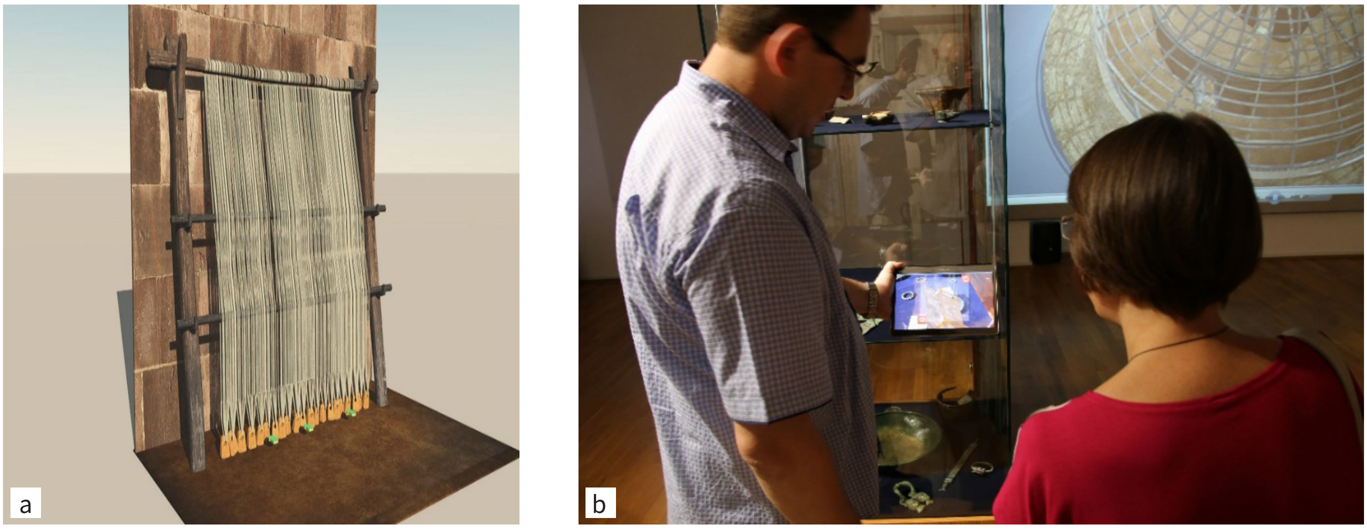

Fig. 13. Augmented reality application for the weight of clay utility in a weaving device: (**a**) large overview of the utility of the weight of clay; (**b**) The augmented reality used in the museum exhibition.

allowing users to enter inside the hot spots with their digital avatar and have access to a series of information in both English and Romanian. Because the user has the freedom to browse any location in the virtual environment, the premises of personalized access to digital cultural heritage are created, they can go in what order they want and they discover and learn information.

5.2. Augmented reality

To create an extended educational framework, two augmented reality application have been developed to support the possibility of in-detail exploration of cultural heritage. One application is usable within the exhibition while the other one can be used outside of the exhibition, in classrooms or other educational spaces. The first application uses QR codes and natural features to present the artifacts within the museum secured display cases in context. Thus, starting from an artifact such as a weight of clay, or an iron decorative tack, or a bronze ornament. The users can see the possible utility of those artifacts directly on the screen of their smartphones or tablets. Figure 13 illustrates the augmented reality application that presents the bigger picture and the utility of the weight of clay positioned in the artifacts display case.

During the testing phase of the augmented reality application, it was found that some phones / tablets are not able to use the natural marker-less tracking system due to the low lighting conditions within the museum exhibition and because of the partial reflections of the display cases thick glass. Therefore, in order to support better implementation on a wider number of equipment, a series of QR codes were added near the artifacts on the glass, as markers, allowing users to access the augmented reality applications that highlight the utility of the displayed artifacts. Figure 14 presents the augmented reality application that illustrates the utility of the iron decorative tack.

While the augmented reality application presented above is suited to be used in context with the artifacts

Fig. 14. Augmented reality application highlighting the use of iron locks and iron decorative tacks: (**a**) large overview of a wooden door with iron decorative elements; (**b**) close-up view of the iron elements.

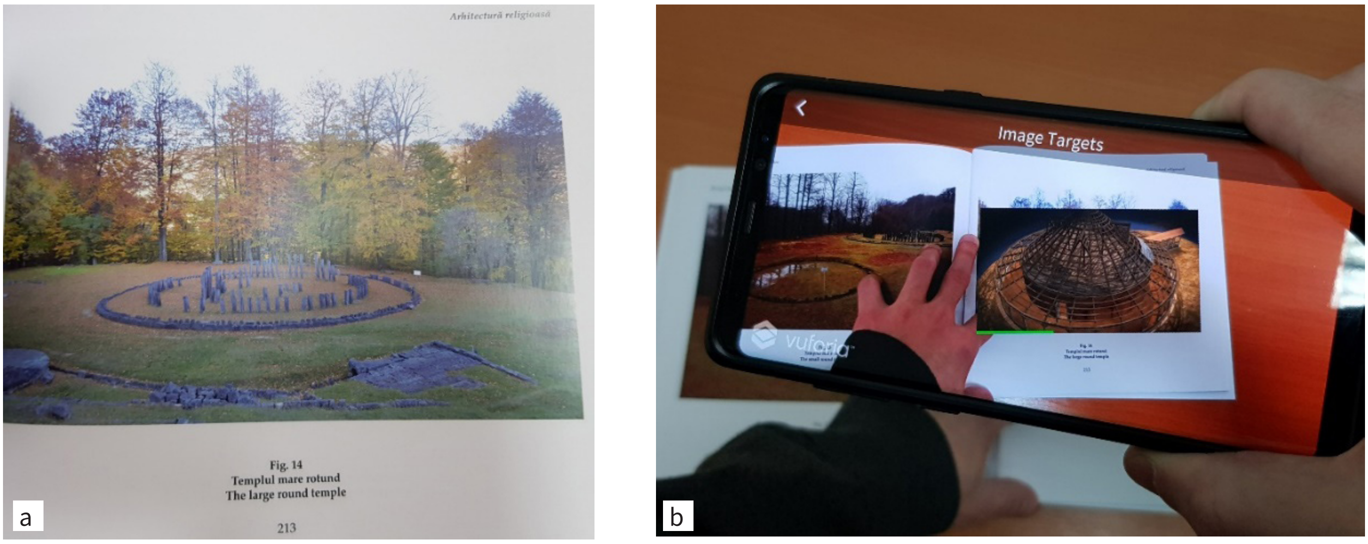

Fig. 15. Augmented reality application for the interactive catalog: (**a**) One of the printed pages from the exhibition catalog that represents and AR marker; (**b**) Interactive 3D animation that highlights the exploded view elements of the large round temple's reconstruction.

Fig. 16. Leap Motion application in the exhibition: (**a**) Visitors interacting with a digital replica of a bronze artifact; (**b**) Young visitors interacting with a column shaft fragment (ANON n.d.)

positioned within the museum's exhibition display cases, the second application has been developed to be used anywhere in combination with the printed catalogue of the interactive digital exhibition. The application can be used also on the online version of the catalog 1 and features a wide variety of multimedia 3D content such as 3D models, video, audio files, images, annotations and text translation in other languages. The augmented reality application called dARcit is described in[35] , the application is presented in Figure 15.

5.3. Interaction device

To stimulate learning and enhancing access to cultural heritage assets, several applications have been developed that use various equipment specific to the games industry or virtual reality.

The scenario followed by all the applications that will be presented below encourages the interaction between the user and the virtual environment, consisting of 3D reconstructions and digitized artifacts and stimulation of curiosity and playful spirit.

The equipment chosen for the interaction with the virtual environment are the Leap Motion sensor, Microsoft Kinect, a haptic device and an interactive table.

For Leap Motion (Fig. 16) an application was created to allow the users to interactively manipulate sets of artifacts that are from the same category, for example iron artifacts, weapons, tools, ceramics, etc.

For Microsoft Kinect an application was created in which the user can interact with 3D reconstructed Dacian monuments. Each 3D model is accompanied by text in Romanian and English, and a set of five 3D models representing Dacian artifacts that have a direct connection to the respective monument. 3D monuments of worship, houses or workshops are reconstructed, and the artifacts cover a wide range of weapons, architectural elements or ornaments. Using gestures, the visitor (Fig. 17) can manipulate each 3D model and can choose a personalized route through the content made available in the application.

A unique application in the museum landscape is the

[35] COMES *et alii* 2019.

Fig. 17. Virtual reality application for Microsoft Kinect: (**a**) Visitor interacting with a digital replica of a ceramic artifact; (**b**) Visitor interacting with a digital reconstruction of a temple.

one developed for a haptic device that allows the visitor to "feel" the 3D model (Fig. 18). In the literature, we have not found articles that report similar applications in museums. On a virtual stage containing ceramic vessels, users can touch with a sphere the outer surface of the digital objects. The application was initially designed for the visually impaired but was expanded as part of the "Museum meet Tech" concept.

Fig. 18. Visitor interacting with the haptic device, by "touching" the digital replicas of real artifacts.

The latest device included in the exhibitions organized in the two museums is a multi-touch interactive table, for which a puzzle application was created (Fig. 19). The application offers three levels of difficulty and the possibility of organizing a competition between two or four players. To increase the degree of difficulty, the texture applied to the puzzle pieces is dynamic in the form of a video.

6. VIRTUAL REALITY ENVIRONMENT DEVELOPMENT FOR IMMERSIVE AND INTERACTIVE HEAD MOUNTED DISPLAY

The final virtual reality environment was developed using the cross-platform Unity engine. The initial version was also developed using Unreal engine, but with the final build, the team decided to switch to Unity. The decision was highly influenced by the team experience, which has used Unity before to create VR and AR applications.

Initially the virtual reality application was designed to work with the initial first edition of HTC Vive, back in 2018, at this stage the application was mostly used to visualize the 3D reconstruction at their true scale and allow interactive navigation though the virtual environment. For the initial build, the authors have worked with the initial tools and resources found within SteamVR SDK paired with Visual studio programming. During this time, the team has started to disseminate the 3D visualization of the proposed

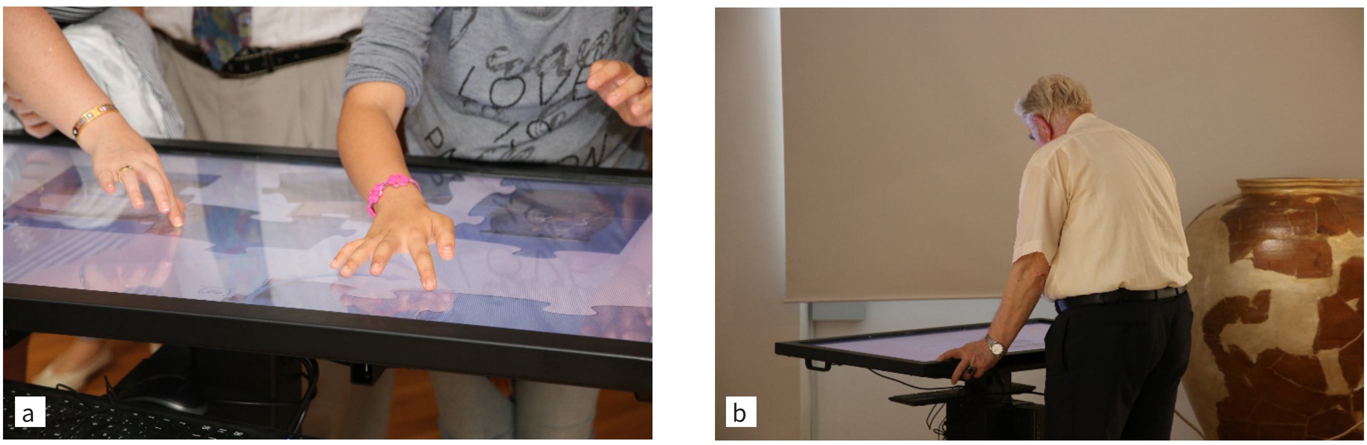

Fig. 19. Application for the multi-touch interactive table: (**a**) Multiple visitors playing puzzle on the interactive table; (**b**) Senior visitor interacting with the multi-touch table.

Fig. 20. Virtual environment presented on-site. In the background the plinths of the temple can be seen. The digital display illustrates the digital reconstruction of temple in the background.

reconstruction on various occasions. One of the most significant occasion on which the virtual environment was presented, was the Open Days of Sarmizegetusa Regia, where the public could explore the real and the virtual monuments (see Fig. 20).

The initial build (see Fig. 21) enabled users to navigate and visualize the reconstructed Sacred Area from Sarmizegetusa Regia. The application had multiple collision meshes at the outer limits of the virtual environment so that the user movement outside the fortification boundaries was limited. The 3D model had multiple collision boxes, which were predefined and position within 3ds Max.

Having the initial virtual reality environment up, the team has started to add 3D scanned artifacts within the environment and define various interactions. In 2019, the research team acquired the HTC Vive Pro headset as well as the wireless adapter to define larger walk areas with the support of the improved base station 2.0.

Up to this stage, the application allowed users to visualize both 3D scanned artifacts and 3D reconstructed monuments as well as the possibility to move within the environment by either walking in the real world, teleporting or using the hand controllers. In order to reduce motion sickness of the users, the research team has decided that within the final build, the movement should be removed from the hand controllers and it should only be done using teleportation and real world movement of the users tracked by the base stations.

Fig. 21. The initial build of the virtual environment.

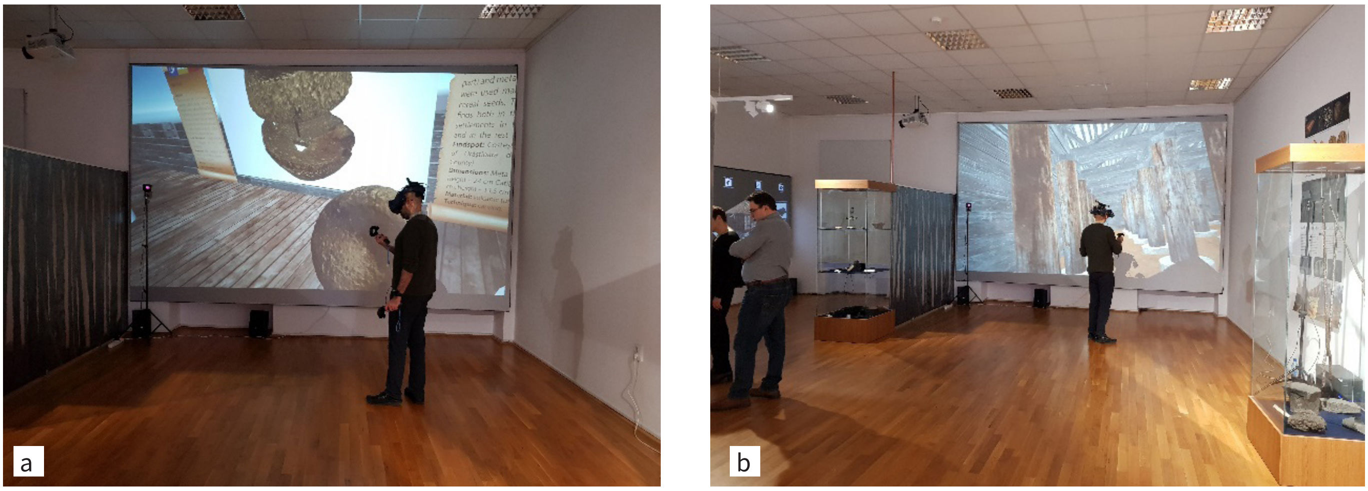

Fig. 22. Virtual reality application: (**a**) Grabbing 3D scanned artifacts within the virtual environment; (**b**) Exploring the 3D reconstruction of a rectangular temple

To develop further interaction, both text, audio and video files were added to the scene. Currently the application supports two languages (English and Romanian) and the users can decide if they want to access either audio files or video files when they are interacting with the 3D scanned artifacts, when they manipulate the objects with the help of the hand controllers. Figure 22 highlights the interaction with the 3D scanned model of a quern and the navigation with a rectangular temple.

The dissemination room for the head mounted display virtual reality application was installed within the real-digital museum exhibition created at the National Museum of Transylvanian History from Cluj-Napoca. This museum also displays the cultural heritage assets within the same location. So that users can both see the digital 3D scanned objects as well as the real artifacts.

As it can be seen, the walking area available within this room is limited; therefore, the teleportation feature quickly allows users to rapidly navigate through the sacred area of Sarmizegetusa Regia.

Having children testing the VR applications, the authors have decided to make a toggle within the application to allow children to visualize and interact with the 3D models comfortably. Initially each object was placed on a pillar with a height of 1.50 meters, allowing adult users to grab the object close to their viewpoint. The height goggle button, which is pressed within the virtual environment, adjusts the height of the pillars and artifacts position to a height of 0.7 meters allowing children to comfortably grab artifacts within the virtual environment.

During the final build developed in November 2019 the authors decided to add more interactivity to the virtual environment, therefore a gravity system was added. The gravity system makes use of the Unity Rigid

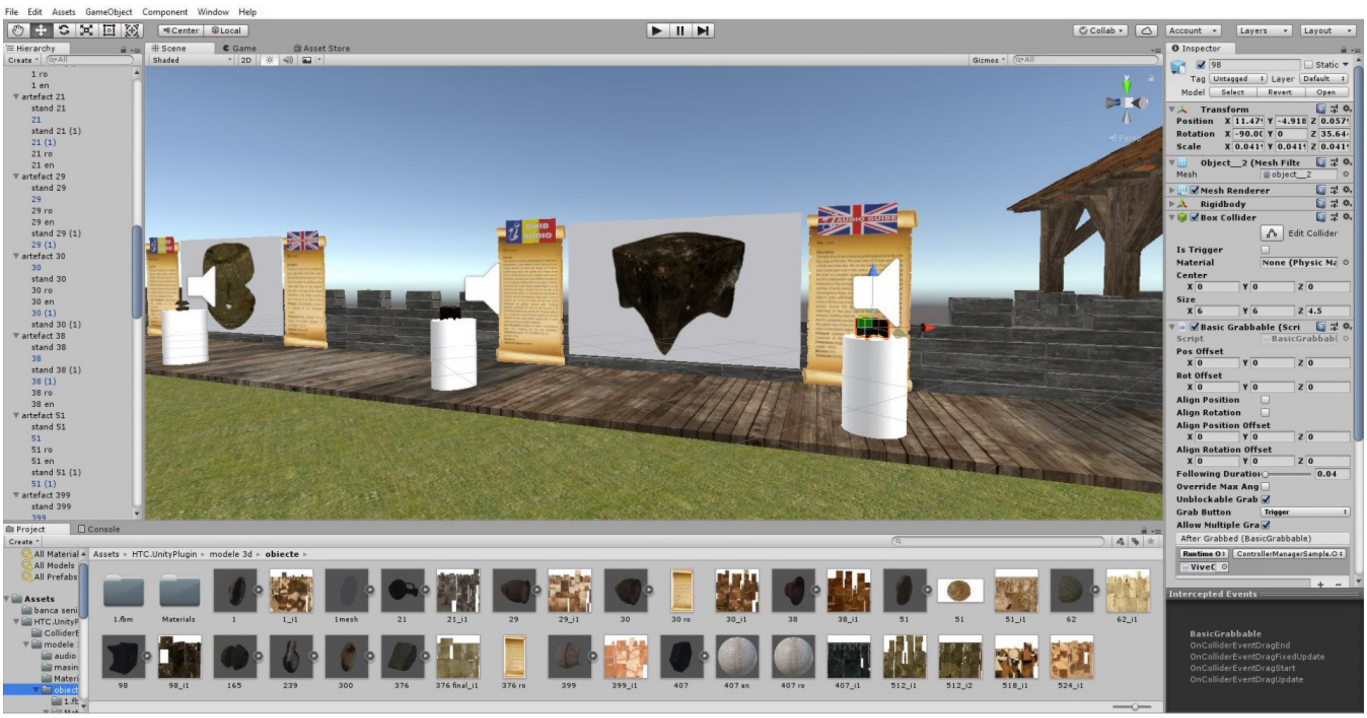

Fig. 24. 3D scanned anvil along with RigidBody and the basic grabbable script parameters definition in Unity.

body mass properties and allows users to let the artifacts levitate within the virtual environment. They can also add rotational movement while the levitation is active, in order to have the artifacts rotating in front of their viewpoint. With this feature, users can easily manipulate in VR heavy items such as the large anvil that is presented in Figure 23. The large anvil weights over 46 kg in reality and has the following dimensions: length (21.5 cm and width 20.5 cm), the detailed 3D model (Anon n.d.), along with its metadata and interactive 3D model (both PDF and web hosted) are available on the project's platform.

The final build was presented in the Romanian Parliament in a special event that commemorated 20 years since the Dacian Fortresses from Orăştiei Mountains have been added to the UNESCO heritage list. The VR application has also been transferred to the new HTC Vive Cosmos headset, which enables for better dissemination in bright environments (such as the one from Fig. 20) without having the need of base stations in order to track the user.

The application was disseminated along with a large model of the sacred area made from plasterboard to better raise awareness regarding the status quo of the Dacian Fortresses from the Orăştiei Mountains.

7. RESULTS

The preliminary conclusions that can be drawn after 3 years of operation of the exhibitions in the two partner museums have shown that the introduction of high-tech devices in the exhibitions does not constitute a barrier for older visitors. The youth appreciates the exhibition concept more, explores and interacts better with the artifacts and learns faster and spends more time in the museum. There is also a social side to this, people from the disadvantaged social categories can interact with the latest technology to which they do not have access at school or at home.

The website was accessed from 102 countries, according to Google Analytics, with an average of about 150 visitors per day and a peak of 1044 visitors in 24 hours. The 560 objects hosted on Sketchfab gathered over 17.000 views with an average of more than 30 views per artifact; while the most viewed one has over 1600 views.

The "virtual-tour" applications have been developed in Unity and are hosted on the Dacit project's webpage[36]. They contribute to the dissemination of CH trough gamification, but due to the size of the files used, a high-speed internet connection is needed. The scanned and 3D reconstructed models are at a high resolution to provide a quality visual experience. An unresolved issue due to technology limitations is the low compatibility of the Unity WebGL applications with smartphones.

During the approx. 6000 hours of operation of the Microsoft Kinect sensors, which are found quite often in museums around world, there were no problems reported regarding their functioning. The only drawback is when large groups of users enter the sensor's field of view the tracking may no longer be as accurate, but the readjustment is automatic and requires the users to exit the sensor's field of vision, after which it resets itself and starts functioning normally again.

The "leap motion" was another sensor used for the interaction between the users and the 3D models, regarding the application that uses this type of hardware there were no problems registered and no weaknesses of the technology were detected.

The regular audience of museum exhibitions with historical themes rarely encounters the haptic device. During the 3 years, it was necessary to calibrate the equipment several times because some users forced its joints too much, out of curiosity. From the surveys conducted during different events, it was found that users are surprised and impressed by the fact that they can "touch" and "feel" a virtual object. We recommend its use, but it requires attention and detailed working instructions to avoid damaging it accidentally.

The interactive table quickly became an attraction point, especially due to the possibility of organizing competitions and setting the level of difficulty. An adult can solve the simplest puzzle in few minutes; while the completion of the most complicated one can last several hours[37]. Issues associated with the interactive table are related to the clean maintenance of the touch surface and if the exhibition is crowded, it should be cleaned once or twice a day. On the one hand, another problem identified was the accidental touching of the surface with clothes, purses or other objects that can produce contact, this occurs especially in autumn and winter.

In order to operate a mixed virtual-real exhibition[38], it is necessary that the supervisory personnel be properly trained regarding the operation and maintenance of the equipment. The applications we used in the two exhibition spaces were set to start automatically so that the staff employed in the two museums only had to turn on and off the computers and multimedia projectors.

In order to keep the interest of the visitors alive and to stimulate their return to the exhibition, the 3D models of the artifacts can be changed periodically.

The project in which the digitization was carried out and the applications described in this paper allowed to obtain many digital artifacts and 3D reconstructions that facilitated the use of a diverse palette of tools in promoting the digitized cultural heritage.

The greatest effort consists in digitizing the artifacts, processing them and performing 3D reconstructions for monuments. Historians / curators / archaeologists as well as engineers / architects and specialized in structures must be present at all stages. They must reach a consensus based on the realities in the field, the archaeological evidence and the analogies of the respective era.

The Dacit project received in 2019 a special mention of the European Heritage Awards jury at the research section as a recognition of the results obtained within the project[39].

8. DISCUSSION

The main objective of this article was to provide useful contribution to the process of recreating the Sarmizegetusa Regia sacred area virtual reality experiences allowing

[36] ANON 2014.

[37] ANON n.d.

[38] ANON n.d.

[39] ANON 2019.

visitors to have the possibility of visualizing the proposed reconstructed Dacian sanctuaries, their fortifications as well as various artifacts. The main strong point of the research was the use of advanced scanning equipment deployed for obtaining accurate digital documentation.

The developed virtual reality application integrated multiple features that enabled better interactions and customizations tailored to the visitor's needs. There are certainly ways to enhance the application in terms of the graphic shader, having better lighting, more content, and more digital interactions. There is also the possibility of adding a multiuser feature to the application, so that users can interact and explore together various cultural heritage aspects regarding the Sarmizegetusa Regia site.

Another development could be enabling the users to jump from one time-period to another, thus better understanding the development of Sarmizegetusa Regia and its sacred area over time. The largest temple has never been finished; this is showcased within the virtual environment and paired with audio files so that users can get new and updated information.

Adding virtual agents capable of human-like behavior within the virtual environment would also increase the immersive effect of the application, there research presented by Machindon[40] highlights the advantages of having one of the key missing factor within virtual reality applications, focused on cultural heritage which is the: human presence.

The most important aspect regarding the development of virtual reality equipment represents the fact that the equipment has evolved, and it becomes less cumbersome to use. For example, the first HTC Vive Head Mounted Display was only usable if the cables were plugged in a computer. Various commercial backpacks that allow users to hold the portable PC on their back appeared in order to reduce the cable connection inconvenient. With the development of wireless adaptors capable of transferring large amount of data, the cable connection between the PC and the headset was removed, the headset being powered by a power bank that can power the headset for several hours. With the latest commercial version of the HTC Head Mount Display - Cosmos, the base stations required to track the user movement were also removed.

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[40] MACHIDON/DUGULEANA/CARROZZINO 2018.

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