# Tangible User Interfaces for Enhancing User Experience of Virtual Reality Cultural Heritage Applications for Utilization in Educational Environment

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Museums are traditionally considered learning environments and are ordinarily used for non-formal education. Physical museums, while being irreplaceable, are limited to a physical space, requiring mobility and physical presence. In addition, traditional exhibitions are not designed for interaction and physical exploration of artefacts. With the focus being shifted from museum exhibits to visitors' experience, utilization of emerging technologies and co-creation of virtual museums not only helps in preservation of cultural heritage, but enhances the dissemination, engagement, and experience, while addressing the mobility and the plurality of voices and perspectives represented. In this work, we designed and developed the School House Virtual Museum with tangible user interfaces based on participatory, interdisciplinary, and co-creative methods with students and a larger community of researchers, artists, and practitioners working on heritage and memory. In a user study with 62 participants, usability and user experience were explored and the potential contribution of such virtual museums to learning, based on critical, cross-disciplinary, and participatory dialogue, both in cultural and educational institutions/programs has been investigated. The results have confirmed that the system has been well designed and developed, and the user experience was largely positive. The responses from educators and students confirmed that the application holds potential as a learning and education tool in either museums, schools, or when used independently.



CCS Concepts: • **Human-centered computing → Virtual reality**; • **Applied computing → Interactive learning environments;**

Additional Key Words and Phrases: Interaction, tangible user interfaces, Virtual Reality, usability, user experience, immersion, education

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## 1 INTRODUCTION

**Virtual Museums (VMs)** are being used more extensively [65] as an independent medium for preservation and presentation of cultural heritage [46, 56] as well as to complement the existing physical museums and their collections [12, 39]. This is essential for wider accessibility of art collections and historical artefacts, but also

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for remote museum engagement during mobility restrictions, such as those imposed by visa regimes, conflicts, economic and other barriers, but also by global travel interruptions and restrictions like those seen during the Covid-19 pandemic. This remote access allows users from any part of the world to engage with the (virtual) museum content, such as narrated stories (written and oral), images and videos (documentary and artistic), and 3D replicas of physical artefacts from the comfort of their homes, workplaces, or other museums. Furthermore, users are enabled to interact and explore and manipulate such content, in particular the 3D replicas, in a way they could not do in physical museums, while the replicas can represent either non-existing 3D artefacts, damaged or partially preserved or fully preserved physical counterparts.

In the past couple of decades, researchers have increasingly explored ways to interact with applications and computer systems within both the real and virtual worlds. This has led to the establishment and development of **tangible and embodied interaction (TEI)** requiring designers and researchers to design the digital together with the physical and explore new types of interactions allowing the user to engage with the computer directly, using as few intermediaries as possible [18, 28]. This in turn allows more liberty in user-centered design, using any means to enhance user experience while maintaining the system efficiency. Similarly, **Tangible User Interfaces (TUI)** have been utilized to provide various tangible forms and materials for allowing input, output, and feedback for their actions as well as manipulation of digital information [35], thus allowing users to literally grasp the data with their hands [51]. Such haptic feedback can enhance the experience and immersion within a VR experience [49].

Haptic feedback consists of three modalities: force feedback, tactile feedback, and the proprioceptive feedback [15]. Force feedback provides information on hardness, weight, and inertia of the virtual object; tactile feedback gives the user a feel of the virtual object geometry, smoothness, slippage, and temperature; whereas proprioceptive feedback is used for sensing the user's body position and posture. The feedback provided in haptic-enabled systems can be active or passive. The former uses computer-controlled actuators to actively exert forces that provide haptic stimulation to the part of the body to which the haptic interface is attached. This method requires additional hardware, such as Phantom device [43], making it more expensive and cumbersome for implementing, handling, and maintaining. The passive haptic feedback does not require actuators and can take various forms. For example, one could use a rubber band between one's hand and shoulder, which would produce passive haptic feedback once the arm is stretched.

At the same time, **Extended Reality (XR)** technologies have become increasingly popular and used in various domains. **Virtual Reality (VR)** in particular has seen a significant increase in sales and usage during the pandemic [57], and given it has become more advanced but affordable, it is moving in the direction of becoming a mainstream technology and platform. VR allows for immersive and emotionally engaging multimedial experiences that can be utilized for delivering educational and participatory museum experiences with playful interaction. Although the interaction in VR has introduced many challenges to the established desktop and mobile direct manipulation techniques, it promises a great potential for various domains, including the presentation of cultural heritage. Therefore, using virtual museums is a great medium for preservation and presentation of tangible and intangible cultural heritage, and VR as an immersive technology has a great potential for enhancing the multimodal experience by providing haptic feedback though tangible interaction.

In this article, the **School House Virtual Museum (SHVM)** is presented and evaluated with 62 participants. The SHVM is based on several years of research in archives and collected material for the period of 1953–1998, including recorded interviews and co-creative research workshops organized with young people with a focus on the events of the 1990s in Kosovo. It is then evaluated through a user study consisting of two experiments with the general public, educators, and students. The aim of the curated content is to facilitate learning and critical reflection over the historical and socio-political events and contexts contributing to ways in which VMs and educational institutions might design and develop pedagogical tools. To facilitate the immersion and provide passive haptic feedback, the tangible user interface has been provided, allowing users to interact with physical proxies from within the **virtual environment (VE)**. The study focus is on the system usability, user experience, immersion, and the potential of utilizing such a platform in the classroom from both the educators' and students' perspective. This work is an extension of the initial work published by the same authors [29].

The main contributions of this work are:

- Investigation of the effect of Substitutional Reality [53] and tangible user interface on user experience in VR cultural heritage applications;
- Providing a replicable model that offers a digital and multifaceted curation that can be applied by cultural institutions, as well as integrated in formal and alternative educational programs, to engage with cultural heritage, memory, and dealing with the past;
- Employment of creative and cross-disciplinary experimentation between VR technologies and social science methodologies, including innovative and critical, as well as safe, explorations of selected spaces, as an alternative means of co-creating historical knowledge;
- Contribute to institutional capacity for dissemination and enhancing public access and aid in the preservation and engagement with vulnerable heritage.

### 1.1 Related Work

Cultural Heritage represents an expression of the ways of living developed by a community and passed on from generation to generation. It is commonly divided and referred to as either intangible or tangible cultural heritage [31]. The former includes oral traditions and expressions, performing arts, social practices, rituals and festive events, knowledge and practices concerning nature and the universe, and traditional craftsmanship [61], as well as political and ideological beliefs that influence cultural practices and history, cyber-cultures in the digital world, and emerging cultural practices that could or will become the heritage of the future [4]. Tangible cultural heritage mainly focuses on places, buildings, monuments, objects, clothing, artwork, and other physical things that can be touched. However, this division is no longer taken for granted, and researchers increasingly focus on the ways they are mutually constituted. The Athena Plus [3], a practice network, whose main objectives are to support digitization and make cultural heritage more widely accessible, stimulate collaboration and facilitate tourism initiatives and services, recommends involving volunteers in the digitization process; E-Inclusion, taking into account the usability requirements and user feedback; analyzing user needs and satisfaction; augmenting traditional information and education tools by using innovative technologies to make heritage more engaging; and establishing synergies with all relevant public and private stakeholders at the local, regional, national, and international levels. Having in mind this continual and necessary reframing of heritage, this work centers participatory design as a necessary methodology in the design, evaluation, and refinement of the SHVM, which is planned to become available in the future physical School House Museum in Prishtina, Kosovo.

Museums and virtual museums are also considered learning environments and are commonly used for nonformal education [19, 58], be it through active learning [9] allowing enhanced engagement with the content and the learning process, thus resulting in enhanced comprehension and participation [14], or through situated learning that takes place in specific environments and contexts in which the learning materials are used, and which are meaningful to the learner [41]. The former can be successfully utilized in educational [6, 30] and cultural heritage serious games [1], delivered on standard platforms and through immersive technologies, such as virtual, mixed, and augmented reality [50, 59, 63]. In all these media, active learning is promoted as the player is required to play, engage, and interact with the content. Similarly, situated learning is intrinsic to VEs and therefore has the capacity to educate the user through engagement and direct participation in contextual and situational experiences.

An additional, intersecting, layer to the engagement and immersion that comes with VR is the potential of participatory-action research principles for generating content, curating collections, and designing active learning tools for a diverse group of users (e.g., museum visitors, students, educators, artists, curators). This is especially true for learning and training aimed at promoting the values of active citizenship, intercultural dialogue, and civic participation. A recent study has shown that high levels of presence, engagement, and immersion can be sustained in archeological VR applications [54] when using 360-degree video storytelling. Forte [21], for example, argues for participatory research in cyber-archeology, which creates "a possible ecosystem ... able to host top-down and bottom-up processes of knowledge and communication" and influences "in a decisive way all the subsequent phases of interpretation and communication." Specifically, museums, whether physical or digital, are sites of learning that allow engaged and combined methods of formal and non-formal learning. Evidence suggests that co-creative, cross-disciplinary, and cross-sectorial educational models [42] ensure plurality and multiplicity in representation and recognition of narratives and histories that might otherwise be omitted in official historiographies and traditional museum exhibitions. Such a research process underpins the outcomes of the VR experience and the learning it generates and is a possible ground for redistribution of knowledge production relevant to underpinning pillars of social justice, which are increasingly central in both education and museums [38, 66].

## 1.2 Interaction and Tangible User Interfaces

Virtual Reality is a technology and a medium that is capable of providing rich experiences through audio-visual computer-generated content reproduced and typically delivered through a VR headset. These experiences and the immersion within them can be further enhanced through embodiment, flow, engagement, as well as by inducing place illusion—a sensation of "being there"—and plausibility illusion—a sensation of the presented scenario actually occurring [55]. Most of the interaction with the environment in real life happens using our hands, by means of touching, grasping, moving, deforming the objects around us. When using computers and interactive systems, this typically happens through input devices, such as mouse, keyboard, game controllers, and tracking systems. Similarly, VR allows us to experience and interact with a virtual environment through different interaction techniques either by using VR controllers or through hand gestures. Typically, four interaction modes are considered: locomotion, selection, manipulation, and scaling, which help us navigate the VE, interact with the objects, change their position orientation or shape, and explore the object or environment details, respectively. Using VR controllers, a certain tactile sensation is obtained. However, controller's shape, texture, temperature, and other properties often do not correspond to those of virtual objects we interact with. Likewise, when interacting with a virtual environment using hand gestures, we might see a virtual proxy of our hands or even the whole body, but we do not get any haptic feedback from the virtual objects we might be interacting with.

Besides interacting with 3D virtual objects and environments, many computer systems require users to make choices and selections. For making selections in a 2D computer system, menus are a commonly used interaction style [44]. While interaction styles and UI design are rather well established for 2D systems, designing these for 3D applications and environments poses some additional challenges, which has resulted in different techniques being explored and taxonomies proposed [17]. Menu selection and interaction for 3D systems can be utilized by directly mapping 2D menus onto 3D space. For example, pop-up and pull down menus could be used [11, 36] by either fixing them to the viewport of the camera like a **heads-up display (HUD)**, or having them float in 3D space, with predefined position and orientation [11, 16]. Alternatively, spin/ring menus could be implemented [22].

A more natural and immersive alternative would be using diegetic interfaces where the UI elements exist as a part of the VE and are visible to both the player and the virtual characters [50]. Such interfaces combined with passive haptic feedback could result in enhanced and even more immersive experiences in various VR applications. This could be achieved by making the user interface tangible. TEI and TUI are not new concepts [18, 28, 35]. They have been used in different domains, such as education, entertainment, edutainment, information visualization, problem-solving, music [34, 51]. Yu et al. [67] have used tangible interfaces that can be held and squeezed in hands while sensing the user's heartbeat in an immersive breathing training experience. Their system provides heart-rate variability enhanced breathing guidance in haptic modality that can be used at any time and place for relaxation and stress release. Similarly, TANGAEON system explores how TEI can be used to support people in mindfulness practice [64]. The system uses a water-based interface in a form of real water in a canister placed over a tablet and allows users to interact with it, thus gaining control over the thought-dissolving process. Furthermore, TUIs have been used for learning and edutainment [7, 20, 27, 68] by means of computationally enhanced toys with interactive sensors and dynamic behavior as various types of manipulatives that promote new play possibilities and foster learning in children. TUI can also improve the performance of hand-drawn 3D sketching [2] and be used in collaborative scenarios [48]. Insko [33] has shown that using physical counterparts to virtual objects significantly increases presence and improves cognitive mapping of the environment. This concept of paired virtual and physical environment is also known as Substitutional Reality [53]. These proxies can be made as low-fidelity so the user sees the virtual object in the VE and can touch the physical proxy that provides haptic feedback based on its shape and structure. However, one needs to take particular care of minimizing the mismatch between the physical object and its proxy, being it the shape, size, weight, texture, or something else relevant to the user and the task [40]. In his work, Simeone et al. [53] have shown that those proxies with low and even moderate mismatch, i.e., similarity in material and variations in tactile feedback, temperature, and weight, were found as believable and had a positive impact on the experience, whereas pairings with significant mismatch had a negative effect on the illusion.

## 2 SCHOOL HOUSE VIRTUAL MUSEUM

### 2.1 Why the School House Virtual Museum?

In 2018, the Municipality of Prishtina initiated a process to construct the Hertica School House Museum. The museum would be located on the site of the Heritica family house, which was used as the "Sami Frashëri" high school between 1992 and 1999. It was also part of the larger schoolhouse system in Kosovo during the time and grew out of particular, and major, political transformations. In 1989, Kosovo's autonomy as one of the eight constitutive units of the Socialist Federal Republic of Yugoslavia was forcefully and illegally revoked. Milosevic's emerging regime in Serbia led this political process, ultimately resulting in the breakup of Yugoslavia. In Kosovo, this disintegration came with a forceful, structural, and systematic political removal of rights. It was accompanied by a violent intervention of the state and the creation of an apartheid like system. The state imposed special measures, whereby schooling became segregated, Albanian primary and high-school directors were fired and school curricula revised. Albanian language instruction at the University of Prishtina was also eliminated. In addition, almost all Albanian public sector workers were expelled from work. The measures included media, healthcare, arts and culture, the police, and the judiciary [24]. With the help of police, school premises, also, became inaccessible. Searching for options, teachers, parents, and community leaders decided on establishing a schoolhouse system. Initially, elementary school teachers began holding classes in their homes but soon all levels of education became organized under this system. Around 3,000 different locations throughout Kosovo, including houses, apartments, basements, and garages were transformed into teaching facilities. The Hertica family house was one of them and saw the graduation of nine generations of high-school students [29]. During the decade, this schooling system came to be considered as the pillar of Kosovo's civic and peaceful resistance movement. It was part of a massive movement rooted in the belief that civil and peaceful resistance offered an alternative to structural and systematic violence.

The first years of the decade were a time of massive mobilization and protest. They also aligned with demands for plurality and democracy occurring elsewhere in the region. As such, they were characterized by massive social mobilization and solidarity and a movement of civil disobedience towards the regime. Remembrance of these events and their collective experiences, however, have become largely subdued by the tremendous impact of the 1989–1999 war in Kosovo. In particular, post-war history and commemorative practices have contributed to creating a rather narrow recollection, often disregarding the multiple social mobilizations and movements of the decade. However, more recently, there has emerged an interest to explore the 1990s for their socio-cultural politics and practices, to critically account for the experiences and histories of this period and more directly engage what is referred to as the "post-memory generation" [26]. In Kosovo, this generation makes up half of the population. It is a generation that has no personal experiences of the war or the schoolhouse system. Consequently, histories and remembrance from, and of, this period have stood in tension with dominant narratives of the war prevailing in post-war Kosovo.

The SHVM enters this complex space of remembrance, as one site of collective and generational memory, with the aim of documenting, engaging, and animating a cultural heritage that can offer a critical contribution. Whereas heritage sites fall into disarray, conservation lags behind, and digitization is in its infancy, institutions and organizations, as well as independent citizen action, have begun vying and intervening for increased preservation and education around such sites. In addition to a 10-year government strategy for cultural heritage, various organizations and initiatives research, collect, disseminate, archive, and engage, through traditional methods and new digital technologies, to make multiple experiences and memories of the past relevant to practices in cultural heritage and for public interests. The SHVM stands at the intersection of these new practices of cultural heritage, reexamining what their role can be amid old and new erasures and denials of agency attesting to resistance against repression and violence. These have come simultaneously from both within and through the significant international interposition in memory politics in Kosovo. Localized initiatives, however, raise important questions about the roles of future museums—as sites of learning for heritage more broadly—allowing new interventions to take place.

## 2.2 The School House VM and Participatory Design

This work is based on several years of collaboration in research and development between the University of Prishtina, Bournemouth University, and the University of Leeds [10, 29, 52, 62]. It encompasses materials collected and designed based on participatory, interdisciplinary, and co-creative methods with students at the University of Prishtina and a larger community of researchers, artists, and practitioners working on heritage and memory. Through a playful, yet genuine, exploration of a difficult and complex past, the design of the SHVM brings to the mix engaged research and learning in a collaborative and co-constructed, pluralist and critical imagining of a site of collective memory. It is based on inclusive modes of representation and interpretation and on increasing understanding of museums as open, living, and networked spaces, where learning and research are transformative and where co-creation and inclusion underpin their vision.

The SHVM provides a curated collection presented as three storylines—Kosovo in former Yugoslavia, Civil Resistance, Schoolhouse (Figure 1)—that build mostly an event based narrative, but one that does not have to be chronologically explored. The chronology presented ("timeline" media in Figure 1) offers a broader context to facilitate an understanding of the schoolhouse system, as well as the contours of the political and social dynamics and power structures that enabled and sustained it. One can enter the journey at SHVM at any storyline in time. The chronology and imagery for the first storyline offers a social history perspective and builds a historical narrative that follows the trajectory of modernization centered on education in Kosovo, in former Yugoslavia. The second storyline offers an overview and exploration of 1990s civil resistance, of the practices and extent of social mobilization, and solidarity, that was enacted in opposition to structural and state violence. It builds a visual account that is based on images with descriptions/captions, a video montage based on collected VHS footage and newspaper clippings from both physical and digital archives, as well as a timeline of events. The third storyline, the schoolhouse, is the most profuse. It includes video-interviews with a diverse group of people (educators, organizers, leaders, and pupils of the school house system), personal and public archival materials (media, school documents, letters, the school newspaper, books, etc.). It is a journey to, and through, a very unique experience.

All three storylines rely on extensive research based on a participatory process using both traditional methodologies and visual and digital research [23]. The research project included over 25 student-researchers who

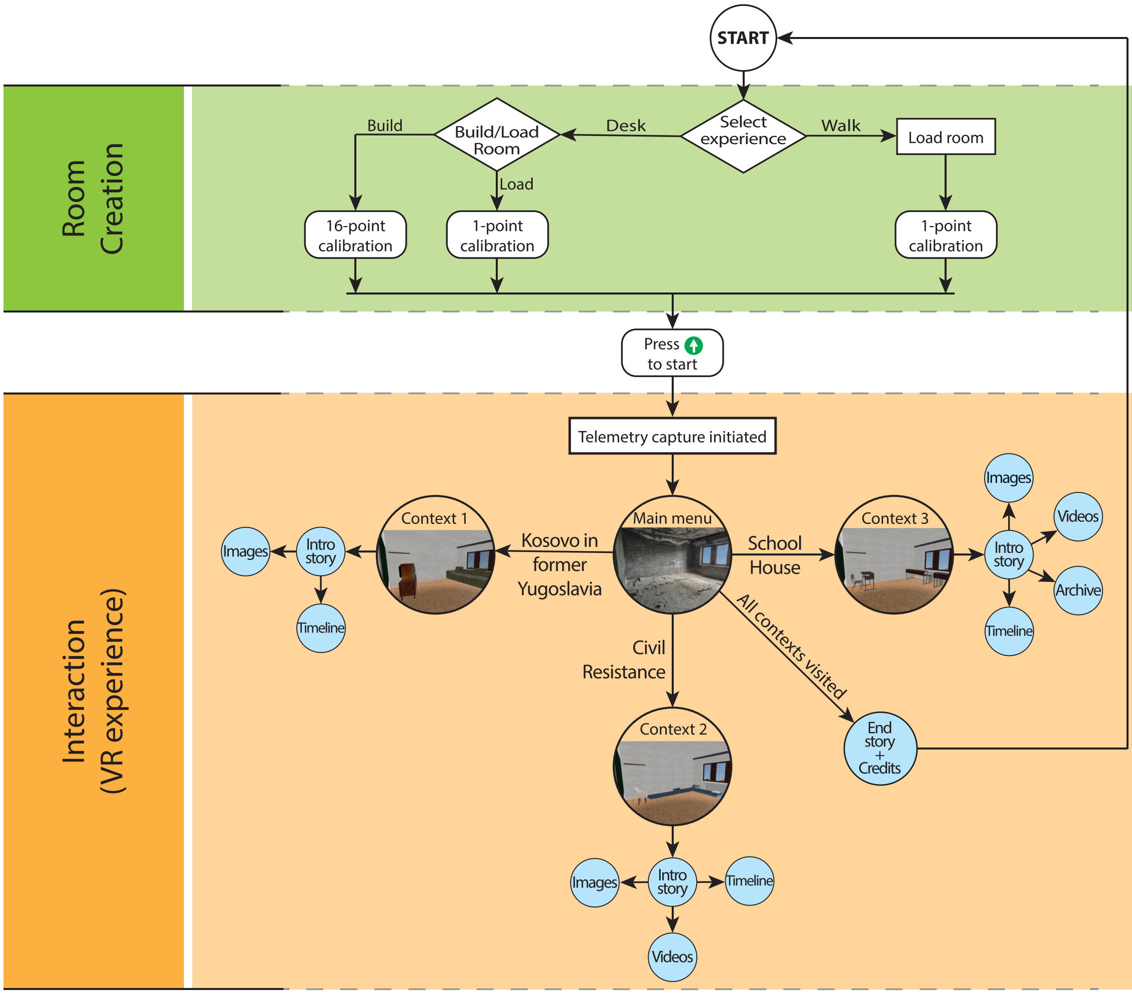


Fig. 1. A flow diagram showing the system structure and the interaction between the user and the system.

together with the PIs designed the research framework to include the collection of primary sources and archival materials, 15 in-depth interviews, 4 focus groups, and multiple exercises. Also, organized in the form of workshops designed around co-production by students, artists, and researchers, these included: on-site sensory ethnography, found sound and production, filming, mapping, and walking exercises, and video-diaries carried out over a period of three years. The work generated was then designed and presented into two online platforms, the School House Museum (https://shtepiteshkolla.net/) and Respace (https://respace.bournemouth.ac.uk/), which organize all the collected materials and provide toolkits for future projects, respectively.

The process was intentionally collaborative and reflexive, based on grounded exercises through which the social, sensory, and material contexts could be identified and re-constructed [47]. Intentionally, the PIs provided significant contribution in the form of auto-ethnographic description and interpretation, having themselves been pupils at the school. The other interviews, and sources, could then be evaluated by the students all together to raise critical questions about memory production, including the dynamics between more historically dominant narratives and those that become silenced. Participation also involved active involvement in a process of

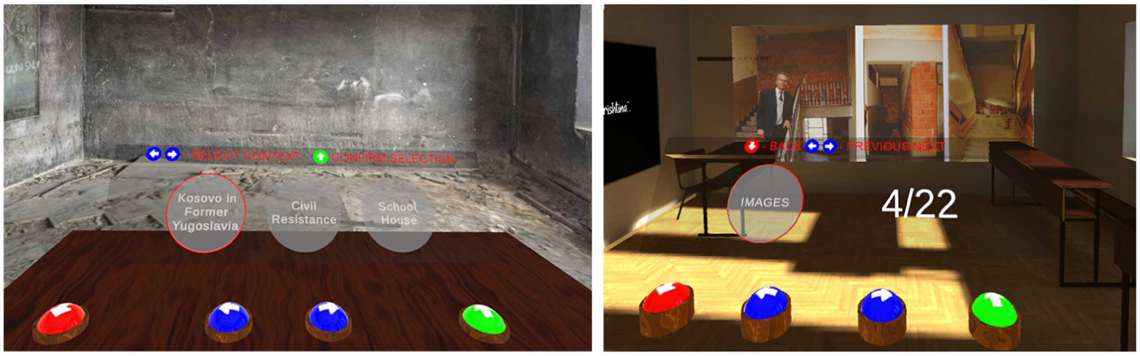


Fig. 2. The two conditions: "Desk" with the context selection in the destroyed room used as a main menu environment (left) and "Walk" with the image section within the schoolhouse context (right; used only in Experiment 1).

inventing, designing, and imagining sites of memory. Ultimately, the research group indicated the importance of sensory and emotional connection that could be provided by presenting the research through a more embodied experience. This then became translated and imagined into a virtual reality experience, where technology becomes a carrier to possibilities of interconnectedness and empathy. Therefore, the SHVM knowingly addresses the need for an interactive design for a future school house museum and process-based research and design for heritage sites. It provides one example of a full circle research process that might be applied to other sites of memory and heritage and engage participatory learning. We gained a number of key insights through this research process that become translated into the SHVM: Technology can become a means of initiating curiosity, visualization of dense historical and archival materials helps learning, intergenerational and personal recountings can be presented and weighed with factual evidences, the curatorial process of the historical and other materials required specialized knowledge and ability to critically reflected on choices. At the same time, the community that was created around the research and SHVM provided for the necessary critical questioning and nuanced understanding of merging together multiple sources and forms of evidence and representation.

*2.2.1 System Design.* The project was built within Unity with the Oculus Quest 2 as the targeting platform. Unity natively supports deployment to various desktop, mobile, and VR platforms, allowing for easy setup of VR camera movement, controller inputs, and hand gestures. The system consists of two main modes: *Desk* and *Walk* experience (Figure 1). Although the main archival content in both experiences is the same, the user interface and interaction are different. In the Desk experience, **Substitutional Reality (SR)** is employed along with the tangible user interface. Namely, the objects around the user that are visible in the virtual environment—the wall, desk, chair, and the buttons, exist and are "touchable" and interactable within the physical environment. In the walking experience, the interface floats in space with no tangible elements, apart from the wall behind the user (Figure 2).

Once the application is started on the VR headset, the user (in our studies, the researcher), is faced with a simple menu with two options: "Build room" and "Load room." Building room is required once in a session to calibrate the position and dimensions of the room, desk, chair, and the interactive buttons. Once this is done, the user can load the built room any time in the future as long as those objects do not move in the real world. Once the room is created or loaded, the player can start the experience.

The first environment the user lands in is the virtually recreated room from the "Hertica" school house in its current, destroyed state. The 3D model is created using photogrammetry and further optimized to run smoothly on the VR headset (Figure 3). From here, the user can select one of the three contexts that will take them into different virtual representations of the same room (Figure 4). These three rooms have been created using traditional

Fig. 3. The room used for the main menu as a virtual recreation of the current appearance of a room in the "Hertica" school house.

3D modelling techniques and software. The appearances of the room in these three contexts complement the story and the corresponding time period, i.e., how the room and the house would have looked at the time. In the "Kosovo in former Yugoslavia" context, the room has a carpet, TV, cabinet, and a sofa to illustrate a typical house from the '80s. In the "Civil Resistance" context, there are mattresses and pillows around the room on the floor, depicting the transition period from a family to a school house. These mattresses and pillows were used for the pupils to sit on at this time. Finally, in the "Schoolhouse" context, there are school desks and benches to resemble a classroom. While there were more of these in the actual house, we removed those that interfered with the desk and the wall projection. Additionally, the 3D room environment and room appearance have been altered, improving the lighting and minor artefacts for the Experiment 2, based on the feedback received in Experiment 1 (Figure 4, bottom). Finally, the music used in the system has been composed for each context based on existing and recorded sounds from the corresponding periods, generating a situated soundscape through context-specific sounds, e.g., pans and keys, representing forms of resistance and rebellion used during the peaceful protests at the time.

*2.2.2 Room Creation.* The room creation is performed through a 16-point calibration process in a real environment with the tangible counterparts of the user interface, e.g., desk, chairs, and buttons (Figure 5). The calibration maps the virtual and physical room, desk, chair, and buttons, thus creating the SR experience. The system is designed so the room and the experience can be created/calibrated in any physical room and with any desk and chair sizes. The calibration process is conducted using the Quest 2 controllers. The instructions for each step, i.e., next calibration point, are displayed on a floating image attached the the left VR controller. The user then clicks on the specified calibration points with the right-hand controller. The desk and chair are initially instantiated as empty game objects that are used to get a straight-line vector for the right, left, and depth calculations. To calculate the scale of the object the position vector of the right-hand controller (when the trigger button is pressed) is used to get a direction vector. An angle is then calculated between the straight line and the direction vector. This angle and the length of the directional vector are multiplied together with a cosine function to calculate the added length needed. Finally, the length is then applied to the object's local scale. The same method is used for the right, left, and depth of the object. However, they differ when applying

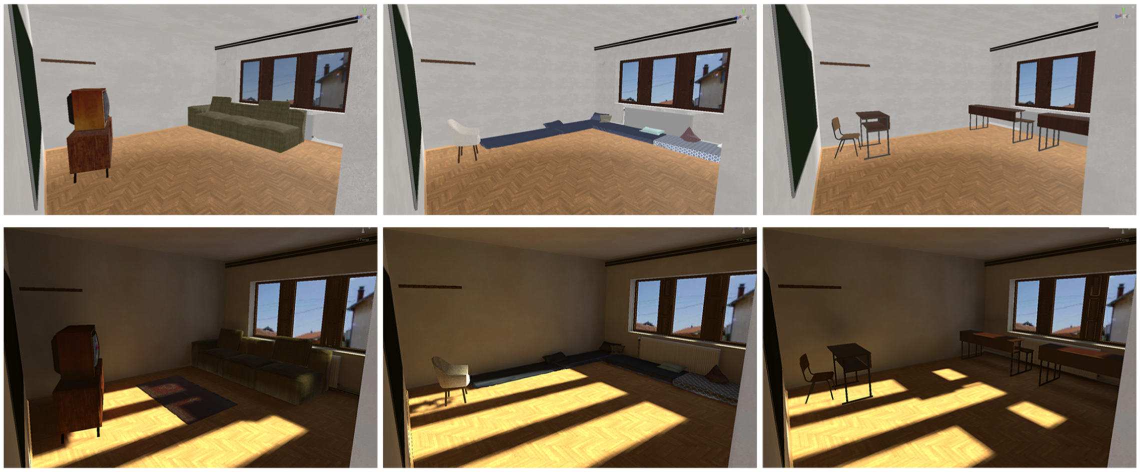

Fig. 4. Three environments used for the three stories/contexts (left to right). Top row: appearance in Experiment 1; Bottom row: improved appearance in Experiment 2.

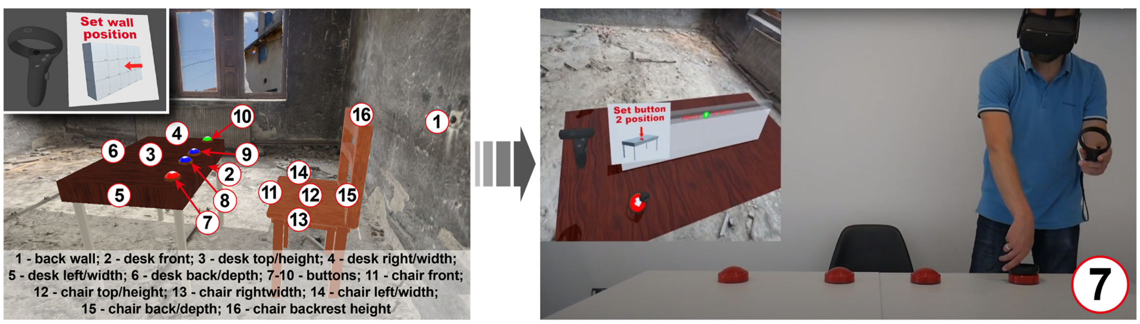


Fig. 5. Calibration of the scene in "Desk" condition. Left: top left part displays the instructions attached to the left controller; numbers show the points of calibration for the room (1), desk (2–6), buttons (7–10), and chair (11–16). Right: a live preview of first button calibration (number 7 in the left figure).

the scale. The right scale gets added to the x-axis, the left subtracts from the local x-axis, and the depth adds to the local z-axis. Last, the desk position is also changed so the middle of the desk does not move, making it look like the desk was only scaled on that side of the object. However, the whole width of the desk would have been increased. The textures are then updated so while calibrating the material is not distorted and looks correct. Legs are also placed after the scale has been done.

The walking experience room setup is completed with a single calibration point—the center of the rear wall (point 1 in Figure 5)—as the desk and chair are not used. The virtual buttons are instantiated and displayed at a fixed distance from the wall and the ground plane (Figure 2, right).

*2.2.3 Interaction.* All interaction in the system, in both modes, is done using Oculus Quest hand recognition and tracking. This allows more intuitive and natural interaction with the system, making it more usable and immersive. The hands are represented as a blue mesh, mapped to the position of the user's (real) hands using outfacing infrared cameras on the VR headset for tracking. The virtual hands have colliders that allow interaction with the virtual world, and in the case of tangible interfaces, to the real-world objects. The interaction with the


Fig. 6. An example of a user navigating the museum content using the tangible interface—red buttons on the desk.

system and the content of the virtual museum is done using the four buttons laid on the desk (in the Desk mode) or in front of the user (in the Walk mode). These buttons are mainly used to go *Back/Level up*, *Left*, *Right,* and *Select/Level down*, allowing the user to navigate the museum content (Figure 6).

In some instances, such as playing videos, the first and the last buttons are used to Pause and Play the video, respectively. However, the instructions on how to use the buttons at any time are provided at the top of the front panel in front of the player. The physical buttons used in the study are light switches but could be easily substituted with any similar objects. The virtual buttons are modeled to match the physical ones and are implemented as game objects in Unity. A spring component has been attached to them to simulate the switch mechanism of their physical counterparts (in Desk condition), which provides passive haptic feedback. When the button is pressed down, the sphere collides with a trigger. Once the collision is detected, the assigned script calls the corresponding function that either changes the highlighted UI, selects a context, image, video, or document to view, or leaves a context or the experience.

*2.2.4 Telemetry Data Capture.* To observe user behavior within the SHVM, telemetry data has been captured in Experiment 2. The data captured is based on events triggered by the users' button presses using their hands. A single event record consists of the following:

- The system time the user pressed the button,
- Which experience the user was using (either desk or walking),
- Which button was pressed,
- Which media type they were viewing (this could be a video, image, introduction, or archive),
- The name of the media shown (this was the actual name of the media file),
- What context the user was in (either "main menu" room, context one, two, or three),
- What was their selection on the desk (this is what option the user had selected on their desk).

This data allows us to see in which room/context they were, what material the users looked at, how they accessed the material, and how long they spent looking at the material.

## 3 USER STUDY

The main aims of this work were to design and develop a virtual museum as an educational tool and to investigate the usability of the system, **user experience (UX)**, immersion with the VR experience, look at the usage patterns of the educators and students, and to explore the potential of the SHVM as a learning and education tool either in museums, educational institutions, or independently.

### 3.1 Experiment 1: Usability, UX, and the Effect of Tangible User Interface

In this experiment, the system has been trialed with the general public in Kosovo trying to validate the usability of the system and investigate UX with it while looking at the two conditions, one of which used a tangible user interface (Desk mode) and the other did not (Walk mode).

*3.1.1 Design.* A between-subject design has been utilized in the experiment. There were two user groups, one that was exposed to the tangible user interface (Desk condition) and the other to the intangible user interface (Walk condition) (Figure 2). In the first condition, the participants were exposed to the SR experience, where all virtual objects (wall, desk, chair, buttons) surrounding the user were paired to their physical counterparts. Unfortunately, due to an unforeseen addition of a slight offset to the horizontal alignment of the buttons on the desk, the physical buttons on the desk have been removed after a few participants in this condition. Nevertheless, the desk and the chair were still tangible and appropriately (vertically) aligned throughout the experience. In the questionnaire, the participants were asked about the basic demographics data (age, gender identity, VR experience) and if they attended any school houses in Kosovo and/or the "Sami Frashëri" school house that was the use case in this study. For evaluating usability and UX, **System Usability Scale (SUS)** [13] and Game Experience Questionnaire [32] were used, respectively.

*3.1.2 Participants.* In the first experiment, 37 participants volunteered, out of which 18 were male, 18 female, and 1 participant declared their gender identity as "agender." The age of the participants ranged from 16 to 50 (with an average age of 30.11). Nineteen participants were assigned to the Desk condition, while the other 18 were assigned to the Walk group. The average reported VR experience, assessed on the scale 0–3 (0-none, 1-basic, 2-moderate, 3-high), was 1.08, with 12 participants reporting they have never used VR. Seven participants attended school houses, and only 1 attended "Sami Frashëri" school house.

*3.1.3 Apparatus.* All the trials took place in a relatively quiet public space. The virtual museum was ported to Oculus Quest 2 VR headset. After the room was calibrated and the experience initiated by the experimenter, the VR controllers were left aside and the participants used the embedded hand-tracking feature and interacted with the tangible (Desk) and intangible (Walk) user interface with their hands.

*3.1.4 Procedure.* Upon arrival, the participants were greeted and given the **participant information sheet (PIS)** and **participant agreement form (PAF)** to read and sign. They were then further explained how to use the system and asked if they had any questions about the nature of the experiment and their task. This was followed by the experimenter selecting the desired condition in the app and, once ready, giving the participants the VR headset and putting the VR controllers aside. The participants were told they could take as much time as they liked exploring the content of the virtual museum and do so in any order. Once they visited all three contexts and returned to the main menu, the end story with the current state of the school house and credits were displayed. Finally, they returned the headset to the experimenter and were asked to fill in the questionnaires.

*3.1.5 Results.* The participants spent 27 m 45 s in the application on average (min 15 m; max 50 m). They spent around 1 m 30 s more on average when using the Desk condition (28 m 29 s) compared to the Walk condition (26 m 56 s).

***Usability Study.*** For evaluating the usability of the system the SUS scale has been used [13]. All questions and the corresponding responses from the experiment are presented in Figure 7. Using the score calculation, as proposed by Brooke et al. [13], the overall SUS score for all participants was found to be 79.46. The scores for the Desk and Walk conditions were 75 and 84.17, respectively (see Figure 8). This confirms that the system has been well designed and the users found it well integrated and easy to to use, with some elements that could be further improved.

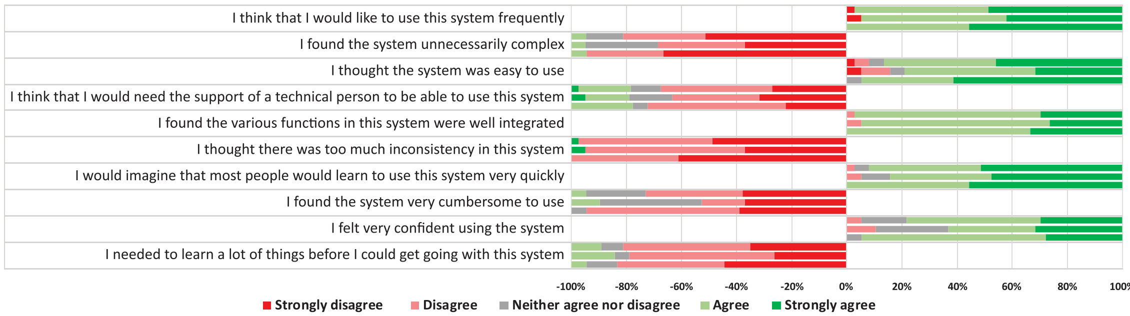


Fig. 7. Questions from the usability questionnaire (SUS) and the distribution of the user responses for all users (top bars), Desk condition (middle bars), and Walk condition (bottom bars).

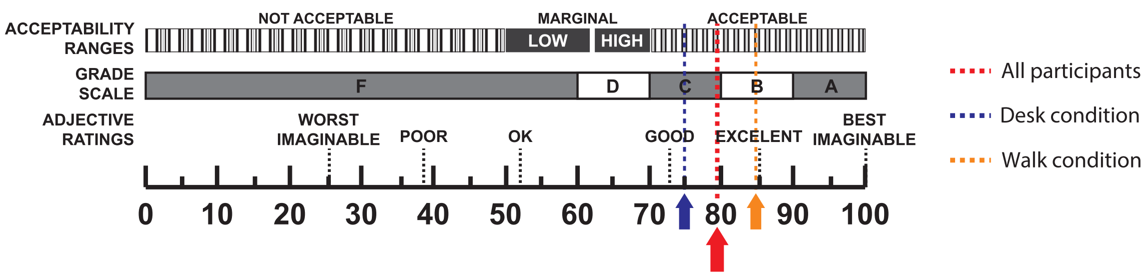


Fig. 8. Grade rankings for SUS scores as proposed by Bangor et al. [5] for all users (red line, 79.46), Desk condition (blue-green line, 75.00), and Walk condition (orange line, 84.17).

Table 1. Questions Used to Evaluate the Presence of the Tangible Interface and the Chair, Desk, and Buttons Proxies with the Corresponding Mean Score Values

| Question | Score (Desk) | Score (Walk) |
|---|---|---|
| The buttons felt real | 3.68 | 3.67 |
| The desk and chair felt real | 3.89 | N/A |

Two additional questions were added to the questionnaire, using the same Likert scale used as in GEQ, that looked at the tangible aspects of the user interface (Table 1). The score mean for the question "The buttons felt real" were 3.68 for the Desk condition and 3.67 for the Walk condition. The second question, "The desk and chair felt real," has been asked only to the participants in the Desk condition and the average received score mean was 3.89, which shows that it had a positive effect on user perception of the virtual space.

***User Experience (UX).*** To evaluate user experience with the SHVM, 27 questions have been selected from the Core module of the **Game Experience Questionnaire (GEQ)** [32]. The questions covered all seven UX components: competence, immersion, flow, tension/annoyance, challenge, negative, and positive effect. The questionnaire uses a 5-point Likert scale, 1 being "Not at all" and 5 being "Extremely." The average scores per question and component are presented in Table 2 cumulatively, as well as per condition (Desk and Walk). The results are overall greatly positive and rather similar across the two conditions. The competence was rated relatively high (3.51) given the lack of experience in using VR. The immersion score was particularly high overall (4.35) and

Table 2. UX Mean Score Values per Question (Q) and per Component (C) on a 1–5 Likert Scale, 1 Being "Not at all" and 5 Being "Extremely"

| No | Component | Question | All | | Desk | | Walk | |
|---|---|---|---|---|---|---|---|---|
| | | | Score (Q) | Score (C) | Score (Q) | Score (C) | Score (Q) | Score (C) |
| 2 | Competence | I felt skillful | 3.42 | 3.51 | 3.11 | 3.19 | 3.72 | 3.83 |
| 11 | | I felt competent | 3.59 | | 3.26 | | 3.94 | |
| 3 | Immersion | I was interested in the story | 4.89 | 4.35 | 4.89 | 4.44 | 4.89 | 4.25 |
| 12 | | It was aesthetically pleasing | 4.14 | | 4.32 | | 3.94 | |
| 18 | | I felt imaginative | 3.89 | | 4.16 | | 3.61 | |
| 19 | | I felt that I could explore things | 4.27 | | 4.32 | | 4.22 | |
| 27 | | I found it impressive | 4.49 | | 4.53 | | 4.44 | |
| 30 | | It felt like a rich experience | 4.41 | | 4.42 | | 4.39 | |
| 5 | Flow | I was fully occupied with application | 4.34 | 3.69 | 4.35 | 3.85 | 4.33 | 3.53 |
| 13 | | I forgot everything around me | 3.56 | | 4.00 | | 3.11 | |
| 25 | | I lost track of time | 2.94 | | 3.11 | | 2.78 | |
| 28 | | I was deeply concentrated in the application | 4.27 | | 4.26 | | 4.28 | |
| 31 | | I lost connection with the outside world | 3.35 | | 3.53 | | 3.17 | |
| 22 | Tension/ Annoyance | I felt annoyed | 1.33 | 1.21 | 1.33 | 1.19 | 1.33 | 1.24 |
| 24 | | I felt irritable | 1.08 | | 1.06 | | 1.11 | |
| 29 | | I felt frustrated | 1.22 | | 1.17 | | 1.28 | |
| 11 | Challenge | I thought it was hard | 1.46 | 1.66 | 1.47 | 1.74 | 1.44 | 1.58 |
| 33 | | I had to put a lot of effort into it | 1.86 | | 2.00 | | 1.72 | |
| 7 | Negative effect | It gave me a bad mood | 1.37 | 1.39 | 1.47 | 1.43 | 1.28 | 1.35 |
| 8 | | I thought about other things | 1.64 | | 1.56 | | 1.72 | |
| 9 | | I found it tiresome | 1.36 | | 1.47 | | 1.24 | |
| 16 | | I felt bored | 1.20 | | 1.22 | | 1.18 | |
| 1 | Positive effect | I felt content | 4.17 | 4.26 | 3.78 | 4.07 | 4.56 | 4.46 |
| 4 | | I thought it was fun | 4.36 | | 4.28 | | 4.44 | |
| 6 | | I felt happy | 4.03 | | 3.63 | | 4.44 | |
| 14 | | I felt good | 4.17 | | 4.06 | | 4.28 | |
| 20 | | I enjoyed it | 4.59 | | 4.63 | | 4.56 | |

The first column represents the order of the question as found in the original GEQ questionnaire and the questionnaire used in the study.

even higher in the Desk condition (4.44). The flow has been rated reasonably high (3.69) with a higher score for Desk condition (3.85) than for Walk condition (3.53). However, this score might have been negatively impacted due to the occasional external noise (e.g., babble of voices), as the experiment was conducted in a public space. Tension/annoyance and negative effect have been both rated very low (1.21 and 1.39, respectively). The average score for challenge, based on the two questions, was 1.66 overall, which is a positive outcome given that this was the first encounter with the VR technology for 32% of participants. Finally, the positive effect was noticeably high (4.26), with an even higher result for the Walk condition (4.46) compared to the score for the Desk condition (4.07).

At the end of the questionnaire, there was an open-ended question, "Is there something you would change, add, or remove from the application, or anything you would like to comment." Twenty participants (54%) responded to this question, of which 11 (57.9%) assigned to the Desk and 9 (50%) to the Walk condition. Although slightly more elaborate, the responses for the Desk scenario were similar to those in the Walk condition. Overall, most of the responses were very positive, including comments such as "*The experience was very educational and creative. I learned new things. Visualization helped me to understand more how School Houses were held during the* *given circumstances. I would highly recommend this experience to everybody.*"; "*I felt I was part of the story for a moment.*"; "*Very impressive, well thought and comprehensive.*"; "*Overall, really cool experience. As someone who had a hard time envisioning that part of history it made me feel closer to it than ever before.*"; "*Very positive, professional, progressive experience. Inspiring too!*" Two participants that experienced the Desk condition reported that it would be better to be able to walk around, instead of sitting. Participants also said that this virtual museum is very important to learn about and experience this segment of history. A few comments for improving the experience were about having more stories, visual content (images and videos), and classes/rooms, improving the quality of the text to make smaller text more readable, improving the room models, and adding more details such as books, school equipment, and so on. Some of these aspects have been addressed for the second experiment (Figure 4). One participant said they would "*shorten the videos a little and reduce the amount of audio-visual material. Focus more on archival material that highlights key events-developments.*" Finally, one participant mentioned it would be better to use the system in a quieter environment. This has also been addressed in the following experiment.

***The Effect of the Tangible Interface on UX.*** To analyze the effect of the tangible user interface on the UX, the **analysis of covariance (ANCOVA)** was utilized with two user groups (Desk and Walk) and multiple independent variables. The **dependent variable (DV)** was the UX score for a particular component (see Table 2), the fixed factor was the condition (Desk, Walk), and the covariates were age, gender identity, and VR experience. The result of the Levene's test was not significant for any of the components, hence the assumption of homogeneity has been met. This means that the relationship between the dependent variable and the covariates is the same in each of our treatment groups.

The test of between-subject effects revealed that age significantly predicts the score for Competence and Positive Effect categories. In both cases, the b-value for the covariate was negative, meaning the covariate and the outcome variables had a negative relationship (as the age increases, the outcome decreases). Similarly, VR experience has also been found as significant ($p < .05$) in Flow and Positive Effect categories. In this case, for both categories, the relationship was positive, meaning that those with more VR experience felt better flow and experienced higher positive effect. This is a very positive result, as this could mean that this VR experience exceeded their expectations based on their prior experience. Gender identity had a significant effect only on competence scores, with male participants self-declaring higher scores. Finally, the effect of condition, i.e., the fixed factor, has been found as significant ($p < .05$) only for the Competence category. This could be due to the fact it takes some time to initially adjust to the idea of tangible user interfaces, as well as the mismatch issue and removal of physical buttons in the Desk condition (the participants still had passive haptic feedback from the desk and chair).

## 3.2 Experiment 2: Immersion and Educational Potential

Given the importance of immersion for such an experience and the rather high score in Experiment 1, we wanted to further explore the aspects of immersion when using the SHVM. In addition, we wanted to further investigate the potential of using the SHVM in an education setting aimed at learning. In this experiment, the system has been trialed with students and educators at the Faculty of Philosophy, University of Prishtina.

*3.2.1 Design.* For the experiment, between-subject design was utilized with two user groups, one consisting of university students and one of educators. All come from the social sciences (sociology, anthropology, history, and psychology). Both groups used the "Desk experience" with the same setup as in Experiment 1. Besides the basic demographics data, the participants were asked for their VR experience and if they attended any and/or the "Sami Frashëri" school house. For evaluating immersion, a subset of 12 relevant questions from the **Immersion Experience Questionnaire (IEQ)** [37] has been used (Figure 9). In addition, a bespoke questionnaire on educational potential of SHVM for both students and educators has been designed.

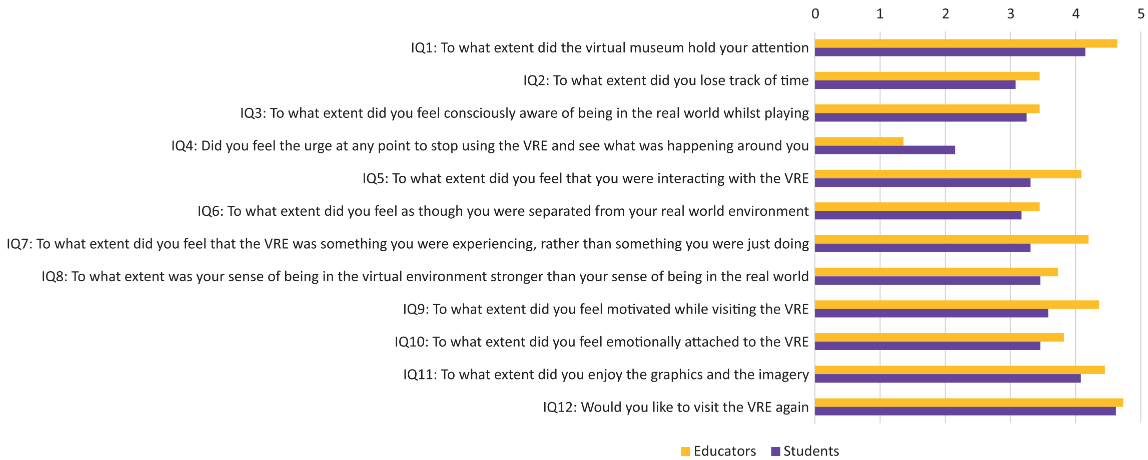


Fig. 9. Questions from the Immersive Experience Questionnaire (IEQ) and the average scores provided by the educators (orange) and the students (purple).

*3.2.2 Participants.* Twenty-five participants volunteered for the study, of which 13 were students and 12 educators. Among the educators, 6 were female and 6 male, with the age ranging from 27 to 51 (average 41.08). Out of 13 students, 11 were female and 2 male, with the age ranging from 19 to 32 (average 22.15). On the scale 0–3 (0-none, 1-basic, 2-moderate, 3-high), the average reported VR experience was 1 for the educators and 0.46 for the students. Five educators and 8 students reported they have never used VR. Eight educators attended school houses, of which 3 attended "Sami Frashëri" school house. No students attended school houses.

*3.2.3 Apparatus.* The same apparatus has been used as in Experiment 1. This time, the experiment took place in a dedicated, quite test room.

*3.2.4 Procedure.* The same procedure has been followed as in Experiment 1.

*3.2.5 Results.*

***Immersion.*** The observed immersion with the experience was rather high for both the educators and students (Figure 9). The highest scores obtained in both groups were for the last question, "Would you like to visit the VRE again." This is promising, indicating that the participants enjoyed the experience. The second-highest rated response was to the first question about the SHVM holding the participants' attention. This indicates that the participants were engaged with the VM and the experience kept them involved.

To analyze the difference of experienced immersion on educators versus students, the **multivariate analysis of covariance (MANCOVA)** was utilized. The fixed factor was the user group, the dependent variables were the responses to the questions, and the covariates were age, gender identity, and VR experience. The result of the Levene's test was not significant for any of the dependent variables, hence the assumption of homogeneity has been met. This means that the relationship between the dependent variable and the covariates is the same in both of our groups.

Overall, no significant effect of the user group on the immersion with the SHVM has been found, $F(12, 8) = 2.14, p = .144$. Although the score means were higher for the educator group, the test of between-subject effects revealed that the only significant difference between the two groups is found for question "IQ5: To what extent did you feel that you were interacting with the VRE?" ($p = .033$). In addition, age significantly predicts the score for IQ5 and IQ6. In both cases the b-value for the covariate was negative, meaning the covariate and the outcome variables had a negative relationship (as the age increases, the outcome decreases). Similarly, VR experience has

Table 3. The Mean Score Values for the First Education-related Questions Using a 1–5 Likert Scale, 1 Being "Lowest" and 5 Being "Highest" across Both Groups—Educators and Students

| Question | Educators | Students |
|---|---|---|
| EQ1. Based on your experience what is/are the major difficulties/challenges faced by students when learning about complex historical narratives? | | |
| Lack of factual information | 3.25 | 3.54 |
| Lack of curiosity | 2.33 | 3.69 |
| Lack of teaching materials | 3.42 | 3.54 |
| Lack of pedagogical tools and examples | 4.08 | 4.15 |
| EQ2. How comfortable would you feel using this Virtual Reality Experience (VRE) in class with/for students? | 4.75 | N/A |
| EQ3. How much would you like to see this Virtual Reality Experience (VRE) to be used in class? | N/A | 5.00 |
| EQ4. How likely is it that you would you use this VRE in class? | 4.58 | N/A |
| EQ5. How much would you like to see this (VRE) to be used in a museum? | N/A | 4.54 |
| EQ6. Which parts did you find most informative and/or useful? | | |
| Introduction story/narrative | 4.33 | 3.77 |
| Archival materials (newspapers) | 4.42 | 3.08 |
| Archival materials (videos) | 4.58 | 4.23 |
| Interviews (videos) | 4.67 | 3.62 |
| Photos | 4.67 | 4.31 |
| Narrative chronology | 4.50 | 4.08 |
| EQ7. Would it be helpful to have designed class activities made available for you? | 4.75 | N/A |
| EQ8. How interested would you be to engage in a VRE project design on this or other topics? | 4.67 | 4.92 |
| EQ9. How much new information did you learn from this VRE about: | | |
| School Houses | N/A | 4.42 |
| History of Kosovo in Yugoslavia | N/A | 3.36 |
| Civil resistance | N/A | 3.55 |
| EQ10. To what extent did you learn new factual information? | N/A | 4.10 |
| EQ11. How much did you like the tangible interface (ability to touch the desk and buttons and be able to sit on the chair) in our VRE? | 4.17 | 4.38 |

also been found as significant ($p < .05$) in IQ8 and IQ10. In this case, as well, the relationship was negative, meaning that those with more VR experience had more negative responses to immersion questions 8 and 10. Gender identity has not been found to have a significant effect on any score.

***SHVM: An environment for learning.*** In the questionnaire, there were 13 quantitative questions and 4 open-ended, qualitative questions on the educational aspects of the SHVM, looking at the educators' and students' perspectives. The first 11 questions using a 5-point Likert scale are presented in Table 3. Some of these were asked to only one group as per their relevance. In addition to Q9, the students were asked, "Which one did you like the most and why?"

The EQ12, used with the educators only, was, "Would you like to have teaching guidelines provided to you or develop them yourself? (0-provided to me; 1-develop them myself; 2-combination of the two)." One educator responded with 0 (provided to them), none responded with 1 (develop them themselves), and 11 educators said they would like the combination of the two.

EQ13 was a "Y/N" question asking, "If you used VR previously, were you able to touch any virtual objects (in the virtual environment) with your body/hands (this does not include VR controllers)?" 11 out of 12 educators responded with "N" to the question, whereas 8 out of 13 students had an "N" response.

The qualitative responses to Q9 corresponded with the quantitative data. Most of the students said that they liked the School Houses the most, as this context had more material, more unique story, it felt real, and it is something that they did not know or had seen much about in the past.

Table 4. The Mean Times (mm:ss) Spent in Different Parts of the SHVM

| Category | Educators | Students |
|---|---|---|
| Total time spent using the application | 24:20 | 19:13 |
| Time spent in introduction story/narrative | 03:40 | 03:50 |
| Time spent looking the archival materials (newspapers) | 00:28 | 00:12 |
| Time spent watching the archival materials (videos) | 03:57 | 02:43 |
| Time spent watching the interviews (videos) | 01:47 | 01:24 |
| Time spent looking at the photos | 04:03 | 04:21 |
| Time spent reading the narrative chronology | 02:18 | 00:45 |
| Time spent in the main menu (Hub room) | 06:33 | 03:40 |
| Time spent in context 1 (History of Kosovo in Yugoslavia) | 04:11 | 04:22 |
| Time spent in context 2 (Civil Resistance) | 04:20 | 03:26 |
| Time spent in context 3 (School Houses) | 09:16 | 07:46 |

The responses to the question, "What difficulties would you expect in integrating VRE in the classroom, besides technological ones?" revealed that the educators are worried about the number of students and the appropriate utilization of the VR headsets, as well as the student attitude and technical limitations and knowledge. For the students, however, there were almost no anticipated obstacles. One student mentioned staff training and another the price of the equipment.

When asked, "What would you change/add/remove in/to/from the VRE in terms of the content?" the educators reported they would like to see more images and video materials and less text, as well as more interaction with the content. Similarly, the students said they would like to have more video materials and more "voices" and voiceover.

Responding to the question, "Describe what you think about the tangible interface (ability to touch the desk and buttons and be able to sit on the chair)—what did you like/dislike?" one educator reported it adds to the immersion and quality of the experience. One participant said "it looks like you are in it, doing something in space and you lose sense of time." Responding to the same question, the students said it makes the experience more interactive, it feels like you are in the real world, and a few of them just said that they liked it very much.

Finally, the responses to the question, "What would you change in the experience in terms of the interaction with the VRE?" were coherent among the educators and students. A couple of participants in both groups asked for more interaction (e.g., picking up objects). One educator said it would be good to have audio feedback on button clicks, and a couple of participants thought it might be better to use swipe gestures to navigate content (instead of the buttons).

***Usage patterns and statistics.*** While interacting with the SHVM, the usage data has been captured by the system (see Section 2.2.4). The first thing extracted from this data are the timings users spent in different parts of the SHVM. The average times for both educators and students are presented in Table 4.

In addition, the data tells us that all the educators visited all three contexts and three of them revisited at least one of them. The most common first context visited by this group was the C1 (75%), followed by C3 (17%) and C2 (8%). Looking at the student participants, 5 out of 13 participants (38%) have not visited all three contexts. 69% of the students visited C1 first, whereas 15.5% visited C2 and C3 as the first context.

## 4 DISCUSSION

A potential reason for the Desk condition being rated slightly lower than the Walk condition in the SUS questionnaire is most likely related to the induced cumulative offset between the virtual buttons and the physical proxies [53], as described in Section 3.1.1. To examine that further, we looked at the scores for the two additional

Table 5. The Responses of the First Seven Participants in the Desk Condition to the Question About the Buttons Feeling Real

| Q: The buttons felt real (Desk) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Participant** | P1 | P2 | P3 | P4 | P5 | P6 | P7 |
| **Score** | 5 | 4 | 3 | 2 | 2 | 5 | 5 |

The responses decrease with the cumulative error and increase again after the recalibration before P6.

questions about tangible aspects of the user interface. We can notice that there was practically no difference between the two conditions (Table 1). However, looking closer at the individual scores for question, "The buttons felt real," we noticed that the initial scores were very high (5 was the highest score) and were then dropping until the full recalibration of the environment after the fifth participant (P5) (Table 5). After that point, the scores about the buttons increased to 5 again. Due to this unexpected behavior, which was not clear to the researchers, the buttons were removed after the seventh participant, which could have been another reason for relatively lower SUS scores for the desk condition. Finally, the usability scores could have been affected overall by the relatively low VR experience among the participants (32% of participants had never used VR before, and 27% had used it only once). Nevertheless, the Pearson correlation between the two variables has been found as low, $r(35) = .25, p = .072$.

The results of the UX study in Experiment 1 were rather positive for both conditions. One could expect slightly higher competence scores for the Walk condition, as it uses a more conventional VR setup. However, it was encouraging that immersion and flow were rated higher for the Desk condition, especially the questions, "I felt imaginative," "I forgot everything around me," and "I lost connection with the outside world." These indicate that the users were fully immersed in the experience, and even more so when the tangible interface was present. The interesting outcome are the responses to the questions in the *Positive effect* category. Two questions ("I felt content" and "I felt happy") had rather higher scores in the Walk condition. This might be due to the simplicity of the Walk condition, where participants with no or little experience with VR technology did not need to worry and stress about the interaction with the VM, but could simply stand and touch virtual buttons. What was really encouraging were the responses to the open-ended question at the end of the questionnaire, which were highly positive. Some of the comments were about the immersive and educational element of the experience and were reasons to proceed with the second experiment and explore these two further.

The results from the immersion questionnaire in Experiment 2 were positive, although indicating some aspects that could be further improved. It was interesting but also encouraging to see higher scores from the educators. Their responses to the open-ended questions equally reflected this enthusiasm and positiveness toward the integration of technology into classrooms. One common theme in the educators' responses was the addition of more images and videos and having less texts. While the students shared the enthusiasm, they expressed concern about the skill set required by both educators and students if this was going to be used in the classroom. They shared the same view on the material used in the experience and had a divided opinion on using the buttons vs. non-tangible swiping interaction. This might be due to the build quality of the physical buttons used in the experiment. We could try using softer buttons with smoother switch operation. Finally, one thing that was mentioned and could add to the overall user experience is addition of interactable objects to the environment. However, given this SR experience works on a premise that all tangible elements are static, we would need to employ dynamic tracking for those objects that the users will be able to pick up and interact with.

Whereas this study did not measure results for educational learning purposes, it provided significant indications of venues for further research and design. The aim of using this experience in the classroom would entail further utilizing the affective, empathetic connections to the stories as a possibility to move to more reflexive and critical engagements with the content. We engaged with multiple research tools and methodologies, including auto and sensory ethnography, found sound, video diaries, and so on [47].[1] One example was the walking and mapping exercise whereby student-researchers drew maps of the route to the school and then produced video-diaries. This brought forth inquiry into the relations between personal and collective experiences and the kinds of narratives that are presented. As such, they can be built into the SHVM with more elaborated guidelines for research, documentation, and presentation.

A critical review [25] of textbooks used in schools in Kosovo shows that their treatment of cultural heritage is rather limited. They offer no explanation of the concept of "cultural heritage" and mainly present material cultural heritage with few references to people's lived experience. The majority of sites and monuments presented also lack historical contextualization and rely on photographic depictions without narrative elaboration. In addition, traditional historiographical narratives often fall short of providing nuanced, engaging, and critical accounts for sites of heritage. In most school curricula, little is said about the importance of museums and cultural heritage for their role in learning about social and cultural memory and history. In addition, whether through traditional textbooks or actual site visits, pedagogical practices convey knowledge that is prescriptive, leaving little or no room for active engagement. Therefore, sensory ethnography was used as part of the participatory action research. It was combined with found sound, walking and mapping, video diaries, and so on, that were used as reflective critical thinking tools in addition to preexisting material, especially the ones used for teaching. Based on post-questionnaire informal interviews, 11 participants with significant experience in cultural heritage and/or educational programs, and 12 educators and students, suggested that the system should be used in schools as well as museums. These would also have to be designed in ways that meet the learning and teaching outcomes and objectives as per the educational level where the tool would be applied. The responses received through administered questionnaires and informal interviews confirm the reputation of VR as an empathy machine.

The SHVM presents visual and historical information that conveys a complex history and is envisioned as a didactic tool. Aimed at younger users (pupils, students, and their educators), it provides a learning tool and a means to engage with research-based processes of social remembrance and forgetting. While specifically engaging the post-memory generation and their educators, it seeks to expand teaching through a pragmatic yet creative engagement with the historical context. The SHVM evokes what is often called the aura of the time [8]. Specifically, our study found that a virtual experience connects participants to the material by making an affective and spatial connection by means of "feeling like being there," as one participant noted. Another reported that they "had goose bumps all over," and another participant cried. At the same time, participants' virtual presence and engagement with the dense archival and historical chronologies, and video materials, contributed to the desire to "spend more time and learn more," as one participant noted. In addition, multiple methods of engagement—such as role-playing, building physical models, and manipulating the virtual environment—could provide for future projects, however, unlike universities and institutions that possess the means, most of such locations globally do not. Therefore, the SHVM is a relevant introduction of VRE for locations that are building technological capacities and more recently devising innovation in cultural heritage. It is about first creating the access by means of less -demanding design that would potentially initiate the introduction of more technologically complex designs and methods.

The fact that the site itself—the house—was significantly destroyed during the war, means that it does not resemble the "original" that was inhabited by the people and events that attach it with relevance. It does not rely on the technological output alone, rather resembles the research process itself. Through archival research it becomes a digital archive of a place itself. The content based on synthesis in video-materials, photos, and interview selections, as well as a particular care given to the soundscape of the experience, offer entry points for the participant to connect with events of the past. In addition, connection with the space of the school, and inclusion of video interviews, becomes particularly important, because it invites questions about the relevance

[1]For the research design, see https://respace.bournemouth.ac.uk/, which provides elaboration on the methodological and pedagogical frame, toolkits, and templates for this project.

of affect, of witnessing and personal experience in history-making and narrative construction. This way, the intersection of the personal with the political serves as ground for reflecting on what is ultimately always a process of selection, when sorting, collating, and narrating archival collections and the construction of past events. By responding to existing learning settings, drawing from analogue collections and teaching, the SHVM digitally re-frames and reconstructs an environment for learning.

## 5 CONCLUSIONS

The application of TUI in the context of cultural heritage applications, such as SHVM, has proven to be very effective, immersive, and suitable for education through virtual museum exhibitions. The proposed solution, despite some limitations, works particularly well and could be used in a classroom, museum, or other public setting. Based on the results obtained on immersion and flow in the GEQ questionnaire, and the qualitative feedback received, it is indicative that the majority of participants in the study preferred the setup with tangible user interface. However, further investigation would be needed to confirm this with more quantitative evidence.

Ongoing global discussions are rethinking museums and cultural organizations as plural and participatory spaces that are embedded in research, foregrounding learning and education. The SHVM aims to make a modest contribution to this conversation. Through a cross-disciplinary and participatory paradigm, it is one tool that can disseminate, archive, and engage digital technologies in making cultural heritage relevant to public interests. As such, it speaks to the relevance of diverse community engagement for sustainable heritage models. It also aims to engage frameworks such as Athena Plus [3] and the UN SDGs [60], which link heritage with educational institutions and practices. Kosovo's own national cultural heritage strategy [45] offers comprehensive guidelines. Specifically, objective *5.3. Education of new generations on cultural heritage* refers to the promotion of alternative uses of heritage sites, intergenerational conversations, and enhanced application of technologies for the documentation and treatment of cultural heritage.

The SHVM was conceived as a needed intervention into the subdued and less-recognized historical narratives around the school house system. It extends an invitation to recognize the implications of traditional pedagogies and curatorial practices for memory and heritage sites. Furthermore, it attempts to produce an environment for learning that would foster a sense of agency and reflexive learning; providing factual information conveyed through story-lines that evoke emotions, attachments, and meanings of this site. As a collaboration between social and technological sciences, as former students of the "Sami Frashëri" High School and with experience in similar projects in the region [50], we consider the project an invitation to explore synergies across sectors and academic fields. It brings together memory studies and participatory methods, civic education, arts, and heritage, to influence formal or informal educational institutions and CSOs adopting innovative, socially inclusive, and participatory pedagogies. The number of digital platforms only recently developed in Kosovo by researchers, artists, and organizations reveals the potential for networking and transforming spaces of learning. More specifically, SHVM is directed towards future collaborations between cultural and educational institutions, bringing museums to the classroom and vice versa.

## 6 LIMITATIONS AND FUTURE WORK

This work investigated how to use participatory design and develop a virtual museum that uses a tangible user interface for increasing the immersion and could be used in a classroom setting for better covering the materials around neglected topics. In the first experiment, we were able to show that the system is well designed and works well. However, every time a user took the headset off their head, the proximity sensor detected it and put the headset in sleep mode. This, consequently, introduced a slight misalignment between the virtual and real objects, mostly affecting the buttons in the desk condition. Unfortunately, we were not aware of this until after the study, which has hindered the strength of the argument that the TUI is more preferable than the classic UI setup. The working solution would be to either disable the proximity sensor or use a 1-point calibration after each user for the same physical setup. In addition, the first experiment did not provide enough qualitative data to draw conclusions on how the system could be used in classrooms. Therefore, the second experiment has been conducted with both the educators and the students, looking at the virtual museum and its potential from these two perspectives. While additional useful data has been collected, given a valuable insight into the immersiveness of the system and its potential effect on the teaching and learning, a larger sample and longer exposure, potentially through a longitudinal study in a classroom or museum setting, would be required to make more generalizable conclusions.

Furthermore, while the desk condition provides a tangible user interface, it is still restricted to a specific part of the virtual environment. One participant reported that it would be good to be able to get up and walk around the room. While this would have its own benefits, it could impose some issues. For example, one advantage of our system is that it could be used in practically any space with a desk and chair, thus requiring relatively small physical space for the setup. This could therefore be used in physical museums or other exhibition spaces by partitioning the physical space into cubicles as small as 2 by 2 meters, while providing tens of square meters of tangible virtual space. Nevertheless, this could be a third mode of the system, in addition to Walk and Desk conditions.

Several participants mentioned that they would like to see more content, mainly the videos and personal stories, and less text. However, some of them have not visited all content available in the SHVM and therefore could have missed the material they reported as desirable. In the future, we plan to merge the SHVM with the online platform [52] that already has a large collection of the archival and research material and enable its exploration and presentation within the tangible virtual museum in a VR medium. In addition, we would add personal objects that are part of the schoolhouse story that the visitors could pick up in both virtual and physical space and that would be dynamically tracked. These objects could be linked to additional (personal) stories and complement the overall presentation and user experience. Finally, dynamic tracking could be explored for the whole system, where even the chair, desk, and other tangible elements can move in physical space and be dynamically remapped in the VE. A future study would be to design very specific guidelines for how to use VR in the classroom and in museums. This would require additional research on current pedagogies and the links that can be built between educational and cultural and heritage institutions. There are insights to be further gained by centering VR as a tool for learning and social conversation on difficult topics.

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