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An augmented reality approach for communicating intangible and architectural heritage through digital characters and scale models

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Abstract
Intangible cultural heritage (ICH) represents living cultural expressions and practices that are part of the heritage of a community, and their preservation and transmission are considered highly important. Various methods and tools have been applied so far for the digitization and dissemination of ICH content including a wide range of technologies. Mobile augmented reality is a promising solution along this path that enables the overlap of digital and real-world information in an engaging and efficient manner. Despite the widespread use of AR in cultural heritage, there are not many studies regarding the user experience, the learning outcomes, and the way in which users observe and interact with the virtual content. This paper presents a mobile augmented reality installation that re-enacts the stages of leather tanning process, adopting a novel approach that augments 3D content upon a physical scale model of an old tannery. This approach pursues to transmit the cultural value of traditional craftmanship to visitors of the building and associate its architectural elements to its history and use. A user evaluation was conducted aiming to measure the users' engagement, learning, and experience using the installation. The encouraging results led to a follow-up study about the impact of the physical scale model on the experience. Two variations of the experience have been studied, one with a physical scale model and one with a digital-only version in a between-subject design. The results of the two studies provide evidence that the proposed approach generated a positive user experience and evident learning gain and was considered easy to use, highlighting its potential to be widely adopted in buildings with architectural value.

Keywords Mobile augmented reality · Intangible Cultural heritage · Human–computer interaction · Architectural heritage

1 Introduction

Spreading the knowledge and promoting awareness about intangible cultural heritage (ICH) are a subject with notable challenges for the scientific community. ICH refers to cultural expressions such as dance, rituals, and craftsmanship that are transferred by communities as part of their cultural heritage. Its preservation has become a topic of international concern and numerous research projects and initiatives have been recruited for that purpose [1]. An important obstacle in the documentation of ICH is the fact that all these expressions are transmitted orally and/or by gestures and are usually modified over time [2]. In contrast to tangible cultural heritage, i.e., monuments, historic cities, or landscapes, where safeguarding is associated to restoration and there are well-established means of documentation, the digitization, preservation, and communication of ICH are still an active area of research and novel approaches are tested for that purpose [3]. Tangible and intangible heritages are inevitably connected but not always distinguishable, as they interact with each other dynamically. Cultural expressions are almost always associated with tangible elements, such as clothes, tools, buildings, or places. To understand the importance and meaning of the first, we need to consider the latter and vice versa [4].

Digital technology can have an important role in the preservation and transmission of culture and in the communication of both tangible and intangible heritage aspects [5, 6]. Cultural expressions of the past have been presented and associated with existing structures and exhibit using techniques such as motion capture, expressive digital

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characters, gamification, and storytelling [7, 8] A number of technologies have been utilized for that purpose ranging from fully virtual representations to augmented or mixed reality solutions. In the latter case, real-world tangible elements, places, and structures are enhanced with images and stories of past cultures, such as location-based games and audio guides, as well as augmented reality experiences [9, 10].

The term augmented reality (AR) refers to the enhancement of the physical world with digital visual and audio content and the seamless blending between them [11]. There have been plenty of manifestations for that purpose, including special hardware worn by users (AR glasses), projection on physical objects or spaces (spatial AR), and AR on handheld devices such as smartphones or tablets (mobile AR). Recent advances in smartphone technology in terms of graphic rendering, processing, and tracking in 3D have made mobile AR technology more efficient, usable, and accessible to a large number of users [12, 13]. However, AR experiences through mobile devices need accurate registration, especially when AR is applied indoors. The virtual elements need to be properly aligned with the physical world to retain the sense of coherence; otherwise, the illusion will be broken and will affect the user experience accordingly [14].

This research aims to study the use of mobile AR technology as a means for the dissemination of intangible heritage related to existing buildings. Older buildings sometimes carry a cultural value that includes both architectural and historical aspects and their visitors cannot directly perceive it. In some cases, places where performances or practices of ICH have taken place in the past nowadays have a different form and use; hence, the connection between memory and history is lost [15]. These missing elements may be communicated to visitors through stories and narration that generate connections between the built environment and its past and may potentially raise awareness about ICH [16]. Therefore, an interesting challenge is to explore possible technological setups and means of communicating the cultural value of these buildings to visitors or bypassers.

In this paper, we present the design and study of a novel approach for communicating the history of an old tannery and the traditional craftmanship of tanning to visitors, using a mobile AR environment that presents animated 3D content on a physical scale model. The proposed solution is targeted to cases where the original buildings have changed use and the connection with the ICH is lost. A prototype system has been developed, through which visitors to the place can learn about the process of leather tanning, the associated tools and equipment, and the locations and structures where this activity has been performed in the past. The information is represented with digital elements and animated characters on top of a physical scale model of a section of the given building through the visitors' mobile device.

We chose to apply augmented reality on a scale model because we encountered certain limitations with AR technology in real-world environments at natural scale. Some of these limitations are presented in [17]. One of the main problems was how to handle occlusions, which occur when obstacles or people move through the environment and make it challenging for current algorithms and devices to display occlusions caused by physical elements in a natural way. This results to an unnatural combination of physical and digital content, which undermines the illusion of an integrated augmented space. Additionally, there were tracking issues at the physical scale that made it difficult to precisely place digital elements and characters in the physical environment, particularly if they needed to align with existing building structures. Conversely, using a scale model allowed us to represent the cultural space's tools and processes more accurately. We believe that a scale model offers several benefits, such as providing visitors with a more complete and holistic overview of the site and aiding their understanding of the cultural space. Moreover, a scale model offers a more controlled environment for visitors to interact with and explore, which can enhance visitors' comprehension and admiration of the cultural space.

We carried out a user evaluation of the prototype AR installation, where we focused on experience, learning, and ergonomics of the approach. We utilize a range of methods, including questionnaires to gather demographic information and assess user experience, as well as video capture and observation to gain insights into user interactions. Additionally, analysis of user logs enabled us to identify patterns of usage and errors. Following some improvements in the prototype that have been based on the results of the evaluation, we proceeded with a second study, where we aimed to examine the effect of the physical scale model on the experience. We performed a comparative study between two versions of the application: a hybrid one with a physical scale model and digital content and a fully digital one, where the scale model was presented in 3D. The results of the two studies led to interesting findings regarding our approach about user experience, learning effectiveness, spatial memory and association, ergonomics of AR, and the combination of physical and digital content. An early version of this work has been presented in [18].

The rest of the paper is organized as follows. In Section 2, related work is described, and the context of this paper is set, while in Section 3, the AR installation and the experiment setup are described. Then, Section 4 presents the user evaluation and analyzes the results. In Section 5, the comparative study is presented along with its results. Section 6 provides a discussion about the findings and finally, in Section 7, conclusions and future work are reported.

2 Related work

2.1 Dissemination of intangible heritage using extended reality

It is widely acknowledged that the use of extended reality (XR) technologies can potentially benefit the presentation and dissemination of intangible heritage. One of the pioneering approaches towards this end has been ARCHEOGUIDE, an early AR system that combined visualization technology and mobile computing in the field of cultural heritage. Visitors of an archeological site could use a special AR interface to watch a 3D reconstruction of an ancient temple, as well as virtual athletes performing in the ancient stadium, while being present in the natural environment and listening to audio commentary [19]. Since then, there have been plenty of prototypes and commercial systems for communicating ICH including mobile apps, immersive environments, projected content, or mixed reality worlds delivered through AR glasses.

Given the fact that ICH is inevitably related to human activity, past histories, and rituals, it comes as no surprise that the majority of AR applications that aim to highlight intangible aspects of heritage are designed for outdoor settings. It has been claimed that AR can be an appropriate medium for creating outdoor scenic spots that inform tourists about ICH of historic cities [20]. Although it is technically harder to use outdoor elements as markers due to variable lighting and shadows, these applications are mostly based on users' location or on selected signs to activate the content.

A simple approach to digitally augment the physical space is to present staged scenes or media triggered through image markers or based on the user's location. For example, in the work of Gheorghiu and Ştefan [6], users of a mobile AR system can view video representations of daily life of past cultures with characters dressed in ancient costumes. A similar environment [21] combines historical visualization with existing landmarks and presents scenes with digital buildings and animated characters superimposed on the physical spot based on target image signs. A deeper comprehension of the local cultural identity through representing and reconstructing entire scenes of a festival is the goal of an app presented by Shih et al. [22]. The authors have implemented and tested three different approaches for AR presentation of the content varying in terms of the presentation spot, the type of content, and the interaction capabilities. In a similar location-based AR application [23], visual information about daily life in a pre-historic settlement is presented to visitors. The information is displayed outdoors based on the users' location and includes 3D reconstructions, images, and videos. Finally, in the work of Boboc et al. [7], a mobile AR application has been developed and tested to present historical information about the life of Ovid using animated characters and virtual buildings. Based on the results of a user study, the authors conclude that such systems may contribute to the accessibility of tourists to intangible heritage, where historical context is recreated using 3D representations and audio content.

In some notable cases, the experience has been enhanced with more interactive and playful elements. Lehto et al.

[24] present a gamified outdoor mobile AR environment, where users interact with digital characters to carry out tasks and learn stories about historical places. In another case, a VR solution is proposed as a means for the sustainability and dissemination of intangible cultural heritage. The authors propose the use of digital technologies to create museum content and encourage public involvement with intangible heritage. They present the early design stages of two interactive exhibitions where users can experience a traditional performing art and a craftmanship in an immersive way [25]

2.2 Connection of intangible and architectural heritage

The use of VR or AR technology can help visitors discover the architectural and historical value of buildings and communicate aspects of intangible heritage associated with them [26]. Banfi et al. [27] describe a process for creating enriched presentations of architectural heritage in extended reality that includes data collection, scanning, building information modeling (BIM), information mapping, and sharing through VR or AR applications. Additionally, Merchán et al. [28] present a collection of good practices for disseminating architectural heritage through AR and describe the design of a mobile AR application that presents scanned architectural models at smaller scale on images working as markers. In a recent review about the preservation of ICH through digital technologies, the authors notice that the AR content that is usually associated with historical architecture may include a multitude of elements such as storytelling, building process, soundscapes, clothing, legends, or interviews with past figures [29].

The augmented content is usually presented inside or outside the buildings using mobile devices, special AR glasses, or projection mapping. In the work of Viinikkala et al., the past history of a cathedral is presented in mobile AR through animated digital characters with the use of Bluetooth beacons for proximity detection [30]. In another work, a reconstructed part of a church enhanced with historical information is presented on mobile devices on top of the physical building [31]. Spatial AR has been used to present digital content on a scale model of the façade of a historical building and inform visitors about its architectural elements and history [32]. Finally, an AR experience using smart glasses has been created for the interior space of a museum. Visitors can walk around areas of the building guided by voices that represent key figures of its past and looking at superimposed digital content relevant to the stories [33].

In a few cases, the experience is presented in VR to ensure that visitors have rich and immersive interactions, even if they are disconnected from the actual physical space. In a recent work aiming to study how different means can provoke communication and interpretation among users, a building and its associated information have been presented using two alternative approaches: an immersive environment with headset and a projected VR environment [34]. In another case, visitors to a museum could view some of its inaccessible spaces through an immersive experience using VR headsets. They had a visiting experience in a virtually recreated old castle, where ghost-style characters presented stories and events of the past [35].

Finally, some systems have used an indirect AR approach to overcome problems with tracking technology and the occlusion of other visitors in public spaces. In one case [17], the mobile AR app attempts to solve the constraints of technology for indoor places by visualizing the real environment using panoramic images. In another application, a rotating screen has been installed in the interior of an old oil production factory, now operating as a museum to present the process in indirect AR. Users rotating the screen could look at the respective areas of the physical building virtually restored, where the operation is presented with digital characters and animated machinery [36].

2.3 Hybrid AR setups for cultural heritage

In recent years, hybrid solutions have been proposed for augmented or mixed reality experiences in cultural heritage that involve the use of physical artifacts. Nofal et al. introduce the concept of “phygital heritage,” i.e., a tight combination of physical and digital elements for the presentation of cultural heritage [37]. The authors claim that the integration of digital content into the physical world is a potential medium for rich playful interactions and communication of heritage and introduce a model to denote the different categories of phygital heritage according to the level of physical affordance and the situatedness of the system.

One possible use of physical artifacts in hybrid environments is for interaction with cultural content. For example, the system proposed by White et al. [38] supported tangible interaction, which was based on 3D-printed replica of an artifact enhanced with sensors; users could hold and rotate the object to control the visualization of digital heritage content. In another work, users held a physical element that resembled and operated like a flashlight, in order to highlight features of exhibits. The augmentation was achieved through projection of expressive 3D visualizations on top of the physical object and was controlled by the user through pointing the virtual flashlight in designated parts of the object [12]. Finally, in the work of Hulusic et al. [39], a virtual museum using a hybrid setup has been created to communicate historical events to younger generations. The museum explores the concept of substitutional reality [40], i.e., the representation of physical elements as virtual objects that users can physically touch or interact with. It includes a physical chair, table, and a set of buttons that participate in the immersive experience.

In other cases of hybrid setups, the AR experience involves a visual blending of physical artifacts and digital content. In a mobile AR application that presents content in designated areas of a museum, the system included an augmentation of a physical scale model of the museum. A virtual model of the building was superimposed on the physical object presenting a reconstructed version of its past form [17]. In another work, projection mapping technology has been used to augment a physical scale model of a settlement. The application presented the advancement of the settlement through time and the impact of the historical eras on its architecture, as well as the process of mastic cultivation, which survived through the years as intangible heritage [41].

2.4 Learning about heritage through augmented reality

AR has attracted the interest of educators in the last decade, as they see in it a potential for learning about heritage. In a study about the use of AR in heritage spaces, teachers mentioned that they consider it a priority for cultural reconstruction and contextualization. It may provide the highest possible level of exploring a heritage piece or place and offer a more holistic experience of understanding and learning about heritage [42]. The authors also conclude that the primary feature in creating AR experiences is the content, and producers of AR experiences focus more on what is being shown and the concepts and facts that are disseminated, rather than visual elements or sophisticated technological features.

Most applications of AR have displayed encouraging results with respect to learning, so far. A mobile museum guide facilitated visitors to effectively switch their focus from the museum space to the digital content and vice versa, and there was a fast learning curve even for visitors that had not used any mobile guide before [43]. In a user study of an AR experience with smart glasses and digital characters in an indoor environment, there was strong evidence of situated learning. Most participants have gained new knowledge through the experience and reported that they acquired a deep sense of the intangible history of the building [33]. In a recent survey about AR in cultural heritage and learning motivation, the authors conclude that AR improves the learning experience and extends it interactively, as it can serve as an automated guide for museums and heritage sites. However, they claim that it is important to distinguish between entertainment and education and include clear educational goals in the AR experience [44]. In another survey, the authors conclude that AR has been used to make the museum exhibits more interesting and attractive to the users and that the use of gamification can generate a collaborative and engaging environment for users, in which they can seamlessly learn about the related subjects [45]. Finally, a study of a mobile AR touring system for heritage education showed that it significantly improved the students' learning achievements and interest compared to a conventional mobile environment without AR [46].

However, learning with AR is still an open subject and there are issues that need further study and consideration. First, it has been noticed that there is a lack of empirical studies on how effective AR is for creating long-term memories, as in most studies, the learning gains are tested immediately after the experience [26]. Then, there may be differences among user groups. For example, an outdoor mobile AR game with digital characters developed for players of all ages has been found more suitable for children than for adults [20]. The school children achieved a flow experience while playing and there was some competition among them. On the other hand, the adults were less satisfied, focusing more on the game graphics rather than the storyline. Finally, in another study, it has been found that users of AR systems with prior knowledge showed interest in the educational and technical possibilities of AR, while those without focused on the attractive elements of the technology, such as visuals and animation [42].

2.5 The focus of our work

Our work is focusing on the connection of architectural and intangible heritage using a hybrid physical-digital setup. We examine the approach of presenting the building at a smaller scale where animated digital characters demonstrate craftsmanship of the past and communicate the story and heritage of the environment. The proposed setup is expected to offer a more holistic view of the process in a controlled environment, while also addressing tracking and registration issues.

Our work also concentrates on disseminating intangible cultural heritage through buildings with cultural significance. In order to achieve this, we have developed a scale model with architectural elements that allow visitors to establish connections between the past history and present form of the building. This approach is expected to enhance visitors' comprehension and appreciation of the cultural space by providing a tangible representation of the building's historical and cultural significance. By combining physical and digital elements, we aim to offer a more engaging and immersive experience for visitors. In order to shed more knowledge about the possible advantages and pitfalls of the proposed approach, we conducted a thorough investigation of the overall user experience, learning outcomes, use of mobile devices during the experience, and the effect of the scale model. We sought to provide new knowledge and insights into the effective presentation of intangible cultural heritage using a hybrid physical-digital setup.

3 A prototype AR installation for an old tannery

The building for which we designed our AR prototype was initially built around 1880 in Syros Island and housed the "Kornilakis Tanning Factory." Nowadays, the building has changed use and hosts the administrative office of the Industrial Museum of Hermoupolis and other services. Even though there are some remaining structures that testify to its former use, the building fails to transfer its history to the visitors. The AR application presented in this paper aims to communicate information about its former use of the building, to inform visitors about the process of leather tanning and its importance in the history of Syros, and to associate the process with the building's architecture.

3.1 Learning objectives and content

The application has the following learning objectives for the visitors: (a) to recognize the basic stages that the leather tanning process consists of; (b) to learn about the conditions, materials, and tools used in each of these stages; and (c) to acquire an experiential understanding of the process.

The process of leather tanning includes eight basic stages, but the content of the prototype is limited to three of them. These are the following:

1. *Soaking*: the hides were soaked in big tanks with water for 2–5 days and were repeatedly stirred with long hooks to get washed.
2. *Tanning*: in big tanks with water and oak bark, the hides were sunk for 7 days to soak up the tanning material.
3. *Finishing*: finally, when the hide is transformed to leather, several finishing operations, such as sanding and polishing, are performed to soften it and cover small flaws [47].

The information required to create the re-enactments of the leather tanning procedure has been gathered through an interview with the curator of the Industrial Museum, documented material about leather tanning in Greece, and

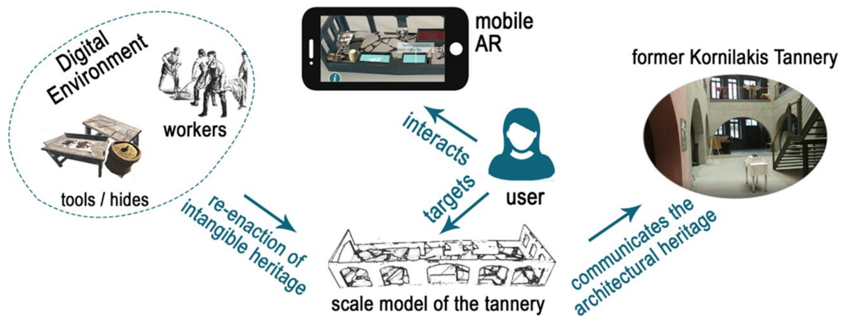


Fig. 1 A concept diagram of the AR installation

Fig. 2 **a** The virtual scene presented on the scale model. **b**–**d** Details of the scene and the 3D characters

a handwritten manual, donated by a former worker of the Kornilakis tannery to the Industrial Museum.

3.2 Overview of augmented reality installation

The AR installation was placed near the entrance of the building, in a place where it is possible for visitors to make a direct connection between the actual space, the scale model, and the leather tanning process that is depicted. All augmentations are demonstrated upon the scale model of the building that includes architectural elements required to present the tanning process. The digital scene contains tools and equipment that communicate the era and the atmosphere of the old tannery. Users can watch the digital characters following the tanning process stage by stage; they can approach close to the scale model to see details of the scene and associate the procedures with the context of the actual building. The creation of these connections is expected to be achieved through the matching of the architectural elements of the scale model with visible structure of the building (Fig. 1).

The narration begins by pressing a start button and the first stage of tanning (soaking) is presented to the users. The basic interactions are enabled through navigation buttons which allow the users to (a) repeat the current stage, (b) move to the next stage, (c) exit the application, and (d) display a pop-up information window. The basic element that guides the narration from one stage to another is the next button (soaking, tanning, finishing). The narration is amplified by visual and audio information. The visual information presented in the application is labels related to objects in the scene and information windows which provide further details regarding each stage. The audio information is sounds that emphasize the actions of the workers (steps, scratches, splashes, etc.) and a narration for each of the stages.

3.3 Implementation of augmented reality installation

The application was implemented in Unity game engine using Vuforia[1] for AR (Fig. 2). The digital characters included in the application have been imported from a free library. Their clothing was adapted to fit the appearance of the era, and the animations re-enacting their activities were

[1] https://www.ptc.com/en/products/vuforia

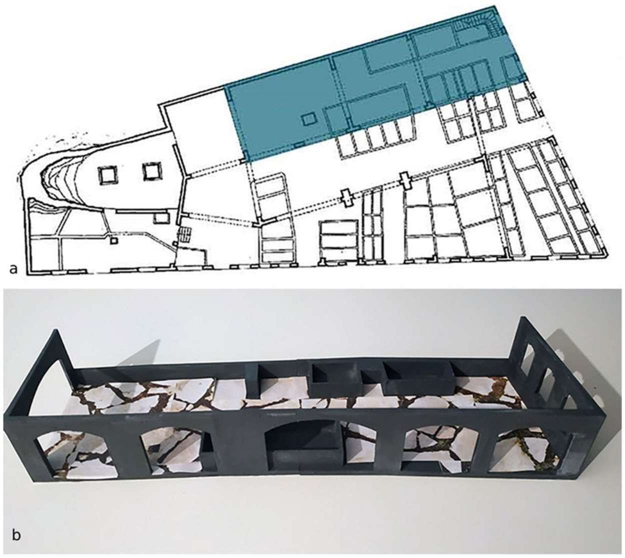


Fig. 3 **a** The area that was used for the 3D representation of the tannery (image adapted from [48]) and **b** the scale model of the tannery

the tanning of the leathers occurred. For the second study, we created a second version of the scale model, where its size has been extended by 150% (see Section 5). A paved floor image has been chosen as the image target of the application, including the necessary visual features to be easily detected and tracked by a mobile device. The image target was pasted on the floor of the scale model to enable more accurate tracking of the ground level, on which the digital objects and characters were placed and animated.

One of the challenges in the implementation of the application was the problem of occlusion between the virtual content and the physical model. To overcome this, we used a depth mask technique[4]. This technique utilizes the depth information captured by the camera to generate a mask that effectively conceals the parts of virtual objects that would be obstructed by real-world objects. By doing so, the virtual objects are displayed in a way that appears to seamlessly blend with the physical environment, providing a more realistic and immersive AR experience for users. For the needs of our research, we incorporated a digital replica of the scale

Fig. 4 **a** The depth mask shader is applied to the mesh of the digital replica of the scale model in Unity engine environment. **b** The AR application with the depth mask shader without the scale model. **c** The AR application with the depth mask shader with the scale model

created in UMotion Pro[2] plugin as keyframing sequences. Lastly, the required tools, furniture, and structures have been placed in the designated parts of the scene according to the scenario.

The application presents the whole process in a part of the building, as shown in Fig. 3. The scale model has been designed in SketchUp[3] based on the building's plans and printed using FDM technology. Its size is approximately 0.36 m × 0.1 m × 0.06 m, and it consists of three walls with windows and doors and four sinks where the soaking and model into the AR scene. This replica was made invisible through a suitable shading technique, while still serving as a volumetric object that concealed virtual objects located behind it. In this way, the occlusion issue was effectively resolved (Fig. 4).

Finally, we included in the implementation a logging mechanism in order to track the position of the phone's camera with respect to the scale model. Given that the image tracker's position is continuously updated in the virtual

[2] https://www.soxware.com/umotion/

[3] https://www.sketchup.com/

[4] Johns, M (2022) DepthMask-Unity-Shader. [Source code] https://github.com/doomlaser/DepthMask-Unity-Shader.git

Fig. 5 Participants interact with the AR installation during the experiment

scene as part of the AR experience, a process records its successive positions at a given rate to track the path of the camera. These values have been processed to extract useful metrics that describe the visitors' handling of the mobile phone during the experience in both the evaluation and the comparative study.

4 User evaluation

The user evaluation was conducted in the former "Kornilakis Tanning Factory." The experiment was set in a spacious and bright place, next to the area that the scale model represented. The positioning of the scale model was carefully considered to ensure that it was well-aligned and oriented in the physical space in order to aid visitors in accurately locating specific elements of the model, such as the arches, within the space. The scale model was placed on a Table 80 cm high. The evaluation pursued to investigate three areas regarding mobile AR technology applied on a scale model: (a) usability, (b) learning, and (c) user experience. Additionally, we sought evidence whether AR technology transfers the cultural value of intangible cultural heritage in combination with the architectural heritage using scale models.

4.1 Process

Initially, participants received a verbal introduction about the purpose and process of the experiment. They were given information regarding the former use of the building and that leather tanning is the process where animal hides are turned into leather. The users were given a short tutorial regarding the usage of the AR installation. The necessity of the briefing lies in the fact that participants had the chance to familiarize themselves with the location, the purpose of the experiment, and the AR installation. After the briefing, participants were asked to complete a questionnaire about demographics and their AR background. In the next stage, they were encouraged to explore the scale model and the physical space. Afterwards, a mobile device, with the prototype application already installed, was provided to the users. They were asked to target to the scale model and move around in order to become acquainted with registration in AR and test the limits in tracking. Once they felt confident with the AR technology, they were urged to press the "Start" button and start the narration (Fig. 5).

After the participants completed their interaction with the AR installation, they were called to answer three questionnaires and provide feedback regarding the experience and the learning content. Finally, the users took a tour in the building, in a quest for locations and artifacts related to the leather tanning process as those were presented to them in the application.

4.2 Measures

The data collection methods adopted during the study consisted of both quantitative and qualitative measures. For the purpose of the survey, we used four questionnaires, one before and three after the AR installation usage. The questionnaires were as follows:

- An introductory questionnaire regarding demographic data, participants' background about smartphones and AR/VR technology, and their familiarity about the leather tanning process.
- The System Usability Scale (SUS) questionnaire, which measures the perceived usability of the AR installation [49].
- The simplified AttrakDiff questionnaire, which evaluates the perceived quality of interactive systems based on their perceived attractiveness, stimulation, and usability. The questionnaire is designed to capture both the pragmatic and hedonic aspects of user experience, as well as the overall attractiveness of the product [50].
- A self-developed questionnaire, relevant to individual parts of the installation using a 5-point Likert scale ("strongly disagree" to "strongly agree") (Table 1).

During the user evaluation process, the participants were observed and recorded through handwritten notes and video recordings throughout their interaction with the AR installation. The evaluator diligently recorded the problematic

Table 1 Questionnaire to evaluate the participants' overall experience

Abbr	Statement
Q1	It was easy for me to see the details of the scene
Q2	The scale model hindered my view of the content while using the AR installation
Q3	The digital worker helped me understand how leather tanning was done
Q4	I understood what was happening in the basic stages of leather tanning
Q5	It was difficult for me to understand what the menu buttons do
Q6	The scale model helped me connect the works with the building where I am

aspects of the interaction in handwritten notes, which included objective features of the user's interaction such as points of difficulty, time taken to complete tasks, errors made, and general demeanor. Additionally, the video recordings captured crucial details such as the user's facial expressions and body language, along with their rationalizations and reactions to the system's functionality [51]. Users were prompt to follow the think-aloud protocol [52] and express their thoughts and intentions while interacting with the AR installation. The investigators transcribed and analyzed any feedback and critical incidents. Furthermore, the embedded logging system tracked the mobile phone's movements in space. All the logging data were processed in terms of path taken, distance covered, and viewing positions and angles. Finally, the investigators noted the users' ability to associate the actual locations of the building with the digital representation of the leather tanning process and in a follow-up discussion, they seek feedback about participant's experience and perceptions of the AR installation The discussion covered a range of topics, including the participant's overall impressions, their perception of the AR installation's ease of use, and any issues or challenges they encountered during the evaluation.

The research adhered to ethical principles for human research, all data collected was anonymized, and video captures were deleted after the analysis was completed.

4.3 Participants

The user evaluation took part 27 participants, 16 females and 11 males, aged between 17 and 65 (mean = 31.4, SD = 12.8). 55.5% of the users were under 30 years old and the remaining 44.5% were from 34 to 65 years old. The users were asked to rate their usage of smartphones using a Likert-type scale (from 1 = "never use a smartphone" to 5 = "very often use a smartphone"). Almost all of them were frequent smartphone users and only one was rarely using it (mean 4.6, SD 0.8). Next, they were asked to rate how frequently they played 3D games.

And they used augmented/virtual reality applications. Thirty-six percent of the respondents had never or rarely played, and only 22% do play often or very often 3D games (mean 2.4, SD 1.4). Regarding the AR/VR application usage, none of the participants responded "very often," 40% have answered that they often use them, and 30% have answered that they never or almost never use them (mean 2.3, SD 1.1). Finally, most participants (70%) declared that they had no or minimal knowledge about the leather tanning process and only 11% had good knowledge (mean = 1.8, SD = 1.08).

4.4 Results

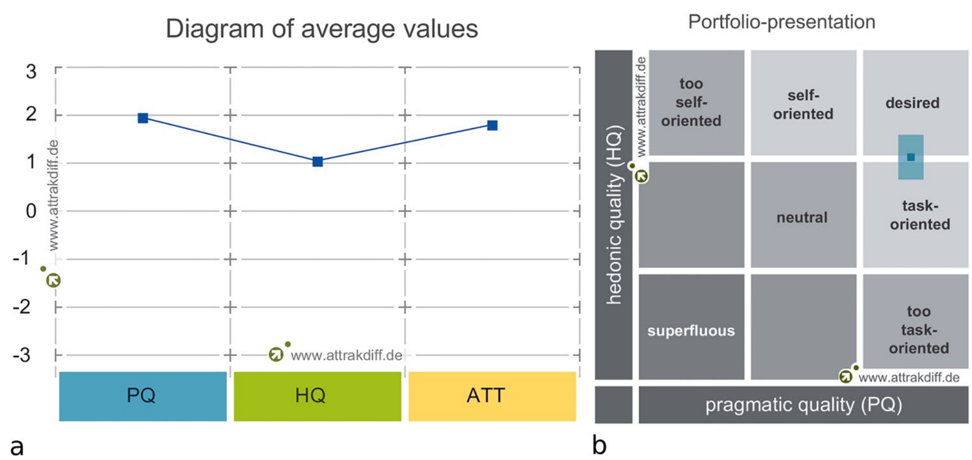
The usage of the AR installation can be defined as successful. The majority of the participants thought it was an interesting experience. Most of the users did not run into any technical problems or other critical issues. Only two users had to reload the application due to tracking issues.

The results from the SUS questionnaire are encouraging and show a high level of perceived usability. The overall value of system usability was 85.83, which can be interpreted as a grade of A +. The level of the value indicates a very satisfactory degree of usability and demand for minor improvements [53].

The results of the AttrakDiff questionnaire are also promising (Fig. 6). The average values indicate that the application was rated high in pragmatic quality (PQ 1.96) and medium in hedonic quality (HQ 1.06). The confidence rectangle shows that the pragmatic quality (PQ conf 0.23) is greater than the hedonic (HQ conf 0.40). The pragmatic quality score of 1.96 suggests that the product is perceived to be relatively high in usability or functionality. The hedonic quality score of 1.06 suggests that the product is perceived to have a lower level of aesthetic or emotional appeal. The confidence interval for hedonic quality is wider than the one for pragmatic quality, which means that there is a high level of uncertainty about the true score for hedonic quality. The results indicate that users successfully achieved their goals using the AR installation, but there is room for improvement in terms of user stimulation and engagement.

The self-developed questionnaire provides us with some further conclusions about the overall experience (Fig. 7). In Q1 (mean 3.88, SD1.05), 60% of participants found it easy/very easy to notice the details of the scene, in contrast with the 20% that found it difficult/very difficult. In Q2 (mean 1.33, SD 0.62), 93% of participants responded that they did not experience visibility issues regarding the scale model

Fig. 6 **a** Average values of pragmatic and hedonic quality. **b** Portfolio presentation of hedonic and pragmatic quality



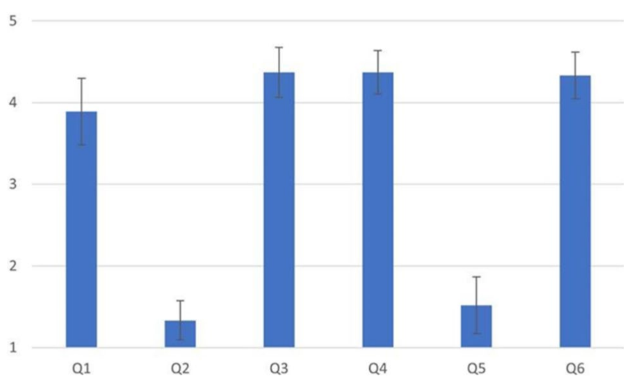


Fig. 7 Average and 95% confidence interval of responses

Table 2 Average values and standard deviation of user log metrics

Metric	Avg	StDev
Time	99.193	30.204
*x*_range	0.248	0.165
*y*_range	0.225	0.125
*z*_range	0.294	0.211
*d*_avg	0.278	0.061
*d*_range	0.272	0.141
rz_avg	62.976	9.251
rz_range	39.148	25.945
*d*_total	3.212	1.732

while using the installation. The results from items Q1 and Q2 indicate a positive evaluation regarding perceived manipulability. The majority of the participants comfortably used the mobile application on the scale model, and some of them suggested a larger scale model. In Q3 (mean 4.37, SD 0.79), 82% responded that the digital worker indeed assisted them to understand how leather tanning was done. Regarding the understanding of the basic stages of leather tanning, Q4 (mean 4.37, SD 0.68), almost 90% of participants were positive and none was negative. Q3 and Q4 items show the highest score on perceived learnability in the survey. After the survey, approximately all participants gained a general knowledge about the leather tanning process. Item Q5 suggests that almost 90% of the participants found it easy/very easy to understand what the menu buttons do (mean 1.51, SD 0.89), which indicates that the interaction with the application menu did not cause any particular problems. In item Q6 (mean 4.33, SD 0.73), 92% of the users managed to associate the re-enactments shown in the application with the building through the scale model, and only 4% of them failed to make such an association.

The data logging from the mobile device has been analyzed to provide further insight into the users' position and movement around the scale model while using the application. The phone's position with respect to the center of the scale model was captured at a rate of 5 times per second. Figure 7 shows a visualization of the captured points from three different views and a typical user path.

The metrics below were exported from the values we gathered per user:

- The range of movement along the *X*, *Y*, and *Z* axes (*x*_range, *y*_range, *z*_range) in meters, calculated as the maximum minus the minimum value per axis and denoting how much did the users move their phone from the front to the back side of the scale model (*X* axis), from side to side (*Z* axis), and from a higher to a lower position (*Y* axis)
- The average distance from the center (*d*_avg), denoting how close the users inspect the model, and the range of distance values (*d*_range), showing how much did the users zoom in or out during the trial
- The average angle around the *Z* axis (rz_avg) in degrees, expressing whether the users were looking at the model mostly from a top-down view (closer to 90°) or from a front view (closer to 0°) and the respective range of values (rz_range)

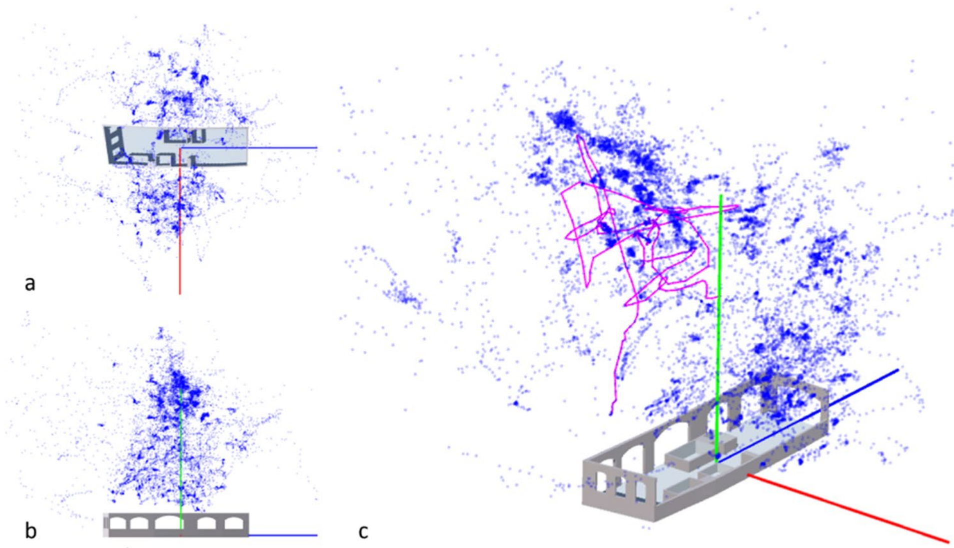


Fig. 8 **a** Top-down, **b** front view, and **c** 3D view of the scale model and the captured phone positions. Positive *X*, *Y*, and *Z* axes are shown with red, green, and blue color respectively. An indicative user path is shown in purple

- The total distance covered during the usage (*d*_total) in meters
- The duration (time) of the application usage in seconds

Table 2 shows the average values and standard deviation of these metrics.

The participants used the application for 99.19 s (SD 30.2) on average. This value is close to the total duration of the narration (92 s). Also well, they traveled 3.2 m (SD 1.732) during the usage on average. The average distance of view was 27.8 cm and the average angle around the *Z* axis was 63°. Those values indicate that the users' point of view while using the application was mostly a top-down view, and they hold the device from a certain distance in which the model fit on the screen. It follows from the data that some participants used the front side to explore the environment (positive *X* value) while others used the back side of the model (negative *X* value). Through analyzing the user paths, it occurs that five participants viewed the model from both sides, which might imply that they had a more explorative stance towards the application. Furthermore, the average *x*_range, *y*_range, *z*_range, and *d*_range values are between 24 and 30 cm, which indicated that the participants generally had the tendency to move their phone while observing the content. They moved closer or further away, along the front or the back side, and lifted or lowered the device to experience different points of view. Corresponding data occurred regarding the angle around the *Z* axis (almost 40°). Yet, these metrics show high variability regarding the standard deviation numbers. When we compared the observation points to the content of the application, it was obvious that many users approached the "tanning" area, probably in quest for more details (Fig. 8).

For deeper analysis, we searched for correlations between the values of the collected metrics and the SUS scores, previous experience in games and AR, and the answers to our questionnaire (Q1–Q6). We found a moderate negative correlation between d_avg and the SUS score ($r = -0.45$), which might imply that viewing the content from a large distance may impact the experience in a negative way. Also, there was a moderate positive correlation between total distance and previous experience ($r = 0.52$), which might suggest that more experienced users might feel more confident or curious to explore the content from various viewpoints. Unexpectedly, we also found a moderate negative correlation ($r = -0.51$) between *z*_range and Q6 (connection of the workings with the building) and a moderate positive correlation ($r = 0.40$) between *d*_range and Q2 (the model hindered the view of the content). Further experiments are required to study possible associations between phone movement and overall experience with mobile AR.

The analysis of the think-aloud protocol along with the conclusions drawn from the video recordings, handwritten notes, and follow-up discussions revealed several issues regarding the users' experience. During the thematic analysis of the think-aloud protocol, the data was carefully examined by transcribing the participants' verbalizations. Furthermore, the data obtained from the examination of the video recordings, handwritten notes, and follow-up discussions was gathered and analyzed. Through this process, recurring patterns were identified that were reflective of the participants' experiences. These patterns were then grouped into potential themes, which included usability issues, user preferences, and content issues. More specifically, some users expressed that a larger model would make the experience more comfortable and engaging, as it would allow them to better see and appreciate the details. Furthermore, users reported that the labeled elements on the scene were confusing, as they were mistaken for clickable buttons. To address this, it may be helpful to revise the labeling or add additional visual cues to make it clear that the elements are not interactive. Some users felt that there was a lack of connection between the space and the scale model and suggested ways to integrate the two more effectively. Few users expressed a desire for a more realistic and immersive experience in the installation. They felt that incorporating factory sounds would enhance the overall experience and make it feel more authentic. Additionally, users mentioned that the narration was difficult to hear at times and suggested the option to rehear it. Although users found the application interesting, many comments were made about the duration of the experience and the level of interaction. To address this, it may be helpful to add game challenges or other interactive elements to increase engagement. One of the participants on the tour stated that "The presented AR installation is the next best thing, since we cannot apply AR in the building itself." Several participants also expressed the importance of permanent AR installations in such places for disseminating aspects of intangible cultural heritage and adding cultural value to the buildings. Overall, these suggestions could help to enhance the installation and create a more immersive and engaging experience for users.

Finally, the results that emerged from the observation of the participants during their tour questing for elements related to the leather tanning process and follow-up discussion are encouraging. Inside the former tanning factory, there were four elements defined. Two of them (tanks and workbench) were defined as obvious and the last two (leathers and task list poster) as unnoticeable. The majority of the participants were enthusiastic about the quest for elements and most of them managed to recognize most of them. More specifically, the so-called obvious elements were discovered by 70% of the participants, and the group of the so-called unnoticeable elements was discovered by 24% of the users. Based on the above conclusions, we can safely presume that AR installations potentially facilitate cultural learning and assist people to link the cultural content with historical buildings and their architectural cultural aspects.

5 Comparative study

Following the encouraging results of the user evaluation, we conducted a study in order to get more insight on the effect of the physical scale model on user experience, learning, and spatial association. First, we implemented some improvements to the scale model and application, based on the findings of the first study. Namely, we increased the size of the scale model by 150% (new dimensions 0.55 m $\times$ 0.15 m $\times$ 0.09 m) and we redesigned the labels on the scene to avoid them being confused for clickable buttons.

For the needs of the study, we compared two variations of the application. The first is the *hybrid* approach, as presented so far, where the content is a blending of the physical scale model with the digital objects and characters. The second is the *digital* approach, where both the model and the content are rendered on the screen of the mobile device. As an implementation, the second variation is the same as the first, with the exception that the scale model is visualized in 3D. Also, users that interacted with this version did not have a physical model in front of them, but just the image of the paved ground operating as an image target.

The space setup and the device were the same as in the user evaluation presented before.

5.1 Process

We decided to follow a between-group design in our study to avoid any learning effects. Therefore, the participants were split into two groups: the "hybrid" group and the "digital" group based on the respective names of the two variations presented before.

Initially, the participants were introduced to the aims and process of the study and were asked to complete a questionnaire about demographic data and previous experience. Then, they filled in a questionnaire about the tanning process used as a pre-test to record their prior knowledge about the subject. After that, they were given a mobile device and had to use the application that matched their group, hybrid or digital. The installation space was prepared accordingly (with the scale model or with a single image target). Initially, they were asked to familiarize themselves with the application by scanning the target and moving the device to view the content from various angles. They were instructed to watch the representation of the process when they felt ready, by pressing the "Start" button.

After their interaction with the application, the users had to fill the same questionnaire about tanning process again, as a post-test. Additionally, they were asked to complete a set of questions where they had to associate the locations and equipment of the digital content to the actual structures of the building. Finally, they rated their experience with the system using a respective questionnaire.

5.2 Measures

The study used quantitative and qualitative measures to evaluate the learning effect and the overall user experience of the two variations of the system. The following questionnaires have been given to users before or after their AR experience:

Table 3 Pre- and post-test questionnaire to measure the learning effect

Abbr	Statement	
QP1	What is tanning?	Open-ended response
QP2	Where were the hides placed in the initial stages of the tanning process?	(a) Under the sun (b) In tanks (c) In a shady place (d) All of the above (e) I don't know
QP3	How were the hides stirred in the sinks?	(a) With the barrels (b) With the tanning paddles (c) By hands (d) All of the above (e) I don't know
QP4	Where is the tanning material (grated acorn) placed?	(a) On the hides (b) In tanks (c) In a shady place (d) All of the above (e) I don't know
QP5	What did they do to the hides when it was ready for tanning?	(a) They skinned it (b) They threw it into tanks of water (c) They removed its hair (d) All of the above (e) I don't know
QP6	What was the slicker?	(a) Tool (b) Hide (c) Workbench (d) All of the above (e) I don't know
QP7	Where was the finishing taking place?	(a) Out in the sun (b) In a shady place (c) On the upper floor (d) All of the above (e) I don't know

- Demographic data (age and gender) and degree of familiarity with smartphones and AR/VR technology.
- A self-developed questionnaire, with open-ended and multiple-choice questions relevant to the leather tanning process used as pre- and post-test (Table 3).
- The simplified AttrakDiff questionnaire for measuring the user experience.
- A self-developed questionnaire to test the spatial association of the processes with the physical space of the tannery. Users were asked to match certain tasks shown in AR with pictures from real space (Table 4).

The evaluation process of the comparative study also involved handwritten notes and video recordings to collect data. The think-aloud protocol as described above was adopted for both user groups. The users' feedback was recorded and analyzed by the investigators. Furthermore, the logging system was also used, and recorded movements of the smartphone around the AR system were provided and analyzed. Further feedback was obtained through follow-up discussions that addressed various topics, such as any difficulties or challenges they experienced during the evaluation.

The study was conducted in accordance with ethical principles for human research. Data that was collected through questionnaires, handwritten notes, video recordings, and the data logging system were analyzed to extract additional insights. All data was anonymized to protect participants' privacy, and video captures were deleted after the analysis was completed.

Table 4 Questionnaire to test the spatial association of the processes with the physical space of the tannery

Abbr	Statement
QS1	Tank to rinse/soften the hides
QS2	Bench where the finishing of the leather was done
QS3	Tank where leather was prepared for tanning-waterproofing
QS4	Workbench with tools

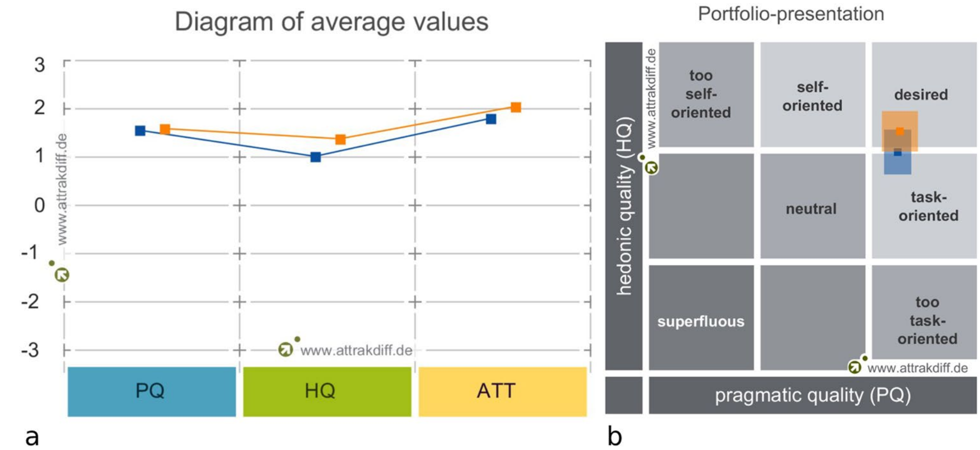


Fig. 9 **a** Average values of pragmatic and hedonic quality in the two groups (orange: hybrid, blue: digital). **b** Portfolio presentation of hedonic and pragmatic quality in the two groups (orange: hybrid, blue: digital)

5.3 Participants

The participants have been recruited through public invitation. In total, 46 users participated, 23 in each of the two groups. Each group had 10 females (43.5%) and 13 males (56.5%).

In the "hybrid" group, the participants were between 16 and 52 years old (mean 30, SD 12.5). 56.5% of the responders were under the age of 30, and the rest (43.5%) were older than 30 years old. Participants were asked to rate how often they use smartphones using a Likert-type scale (from 1 = "never use a smartphone" to 5 = "very often use a smartphone"). Nearly all of them were frequent smartphone users (mean = 4.6, SD = 0.8). They were also asked to rate their frequency of playing 3D games. Sixty-five percent of the respondents had never or rarely played 3D games, and only 17% play often or very often (mean = 2.2, SD = 1.2). Lastly, they were asked to rate their familiarity with augmented and virtual reality applications. Regarding the AR/VR application usage, 13% of the participants responded, "very often" or "often," and 48% that they "never" or "almost never" use them (mean = 2.3, SD = 1.2).

In the "digital" group, the participants were between 16 and 44 years old (mean 24.3, SD 7.1). Eighty-three percent of the participants were under the age of 30, while only 7% of them were over 30 years old. Regarding the frequency of smartphone usage, almost all participants claimed to be frequent users (mean = 4.7, SD = 0.5). As per the frequency with which participants were playing 3D games, 43% of them answered never or rarely, and 39% of them answered often or very often (mean = 2.9, SD = 1.4). Finally, in relation to AR/VR application usage, only two participants responded "often/very often" (8.5%), in addition to 56% that responded they never or almost never used AR/VR applications (mean = 2.2, SD = 0.9).

6 Results

The use of both variations of the installation was generally successful. Most users considered the experience quite interesting and none of the participants faced any serious technical issues.

The results of the AttrakDiff questionnaire are also encouraging. Figure 9 presents a combined diagram of the pragmatic and hedonic quality of both groups. The values in orange color correspond to the "hybrid" group and those in blue correspond to the "digital" group. The average values indicate that the "hybrid" group rated the experience slightly higher in terms of pragmatic quality (PQ 1.60) than the "digital" one (PQ 1.55), indicating that the hybrid version was more useful and functional. Also, in terms of hedonic quality, participants from the "hybrid" group rated the experience higher in terms of preference (HQ 1.38) than those in the "digital" one (HQ: 1.01). The AttrakDiff results indicate that the "hybrid" group (Att 2.07) rated their experience with the AR installation higher based on perceptions of quality and attractiveness than the users in the "digital" group (Att 1.8), indicating that they found the hybrid version more enjoyable and aesthetically pleasing. Finally, in the portfolio presentation (Fig. 9b), it is evident that the hybrid version is placed in the "desired" category. The results of the AttrakDiff questionnaire suggest that the "hybrid" group had a more positive experience with the AR installation than the "digital" group, as indicated by higher ratings in multiple categories. These findings suggest that the hybrid version, which combined physical and digital elements, may have been more engaging and enjoyable for participants. Overall, these results are promising and suggest that the hybrid approach could be a successful strategy for enhancing user experience in similar contexts.

The pre- and post-test consists of one open-ended question about defining the term "leather tanning" and six

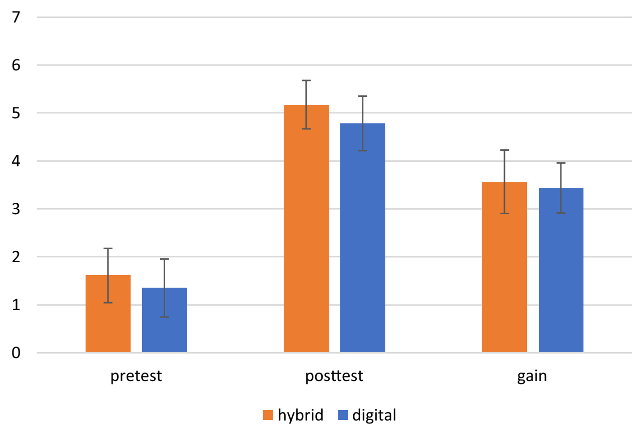


Fig. 10 Average scores of pre-test, post-test, and learning gain for the hybrid and digital group. Error bars represent 95% confidence intervals

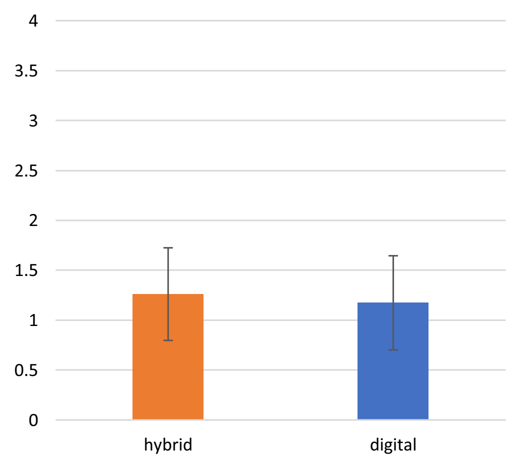


Fig. 11 Average scores of spatial association test and 95% confidence interval for the hybrid and digital group. Error bars represent 95% confidence intervals

multiple choice questions, two for each of the three stages included in the application (soaking, tanning, and finishing). The responses to the test were graded on a scale from zero to seven, based on the correct number of answers. For every participant, the gain, i.e., the difference between the two tests, was calculated. The results in both groups show similar outcomes. In the pre-test, the "hybrid" group had an average score of 1.6 (SD 1.3), while the "digital" group scored 1.34 (SD 1.4). In the post-test, the scores were, again, similar (hybrid group: mean 5.2, SD 1.2; digital group: mean 4.8, SD 1.3). In both groups, there was a considerable gain. The average gain of the "hybrid" group was 3.6 (SD 1.5) and of "digital" group 3.4 (SD 1.2). An independent samples *t*- test showed no significant differences between the two groups in terms of learning gain (Fig. 10).

Table 5 Average values and standard deviation of user log metrics in both groups

	Hybrid		Digital	
	Avg	StDev	Avg	StDev
Time	126.017	59.740	99.374	21.996
*x*_range	0.341	0.274	0.243	0.228
*y*_range	0.242	0.140	0.185	0.115
*z*_range	0.423	0.245	0.322	0.221
*d*_avg	0.347	0.075	0.369	0.070
*d*_range	0.319	0.202	0.230	0.154
rz_avg	64.543	6.829	61.064	7.236
rz_range	33.586	18.675	24.399	15.496
*d*_total	5.263	4.812	3.270	3.040

Regarding the spatial association between the leather tanning process and the building, the results of the test were rated on a scale between 0 and 4 based on the number of the correct answers. The results show that users of both groups had difficulties in associating the digital content to the actual space and no significant differences have been found between them (Fig. 11). Participants belonging to the "hybrid" group answered the questions correctly on average with a score of 1.3 out of 4 (SD 1.1), while the respective results of the other group were 1.2 in average out of 4 (mean 1.2, SD1).

The users' log data have been collected and analyzed using the same metrics as in the user evaluation and the results are presented in Table 5. For a detailed description, see Section 4.4. Although there are some notable differences in the average values between the two groups, especially in the total time spent, path, and range of movement in the *X* and *Z* axes, the independent samples *t*-test showed no statistical significance. Comparing the values to the respective metrics of the first experiment (Table 2), it is evident that the larger scale of the environment (in both groups) affected the users' movement (see *x*_range, *y*_range, *z*_range, and *d*_total) and distance from the center of the environment (*d*_avg). On the other hand, the average viewing angle in both experiments seems to be persistent slightly above 60°.

We followed the same meticulous approach as previously described in Section 4.4, utilizing the think-aloud protocol alongside multiple sources of data, including video recordings, handwritten notes, and comments in follow-up discussions, to conduct a thorough thematic analysis of the participants' experiences. The themes that emerged from the analysis included user goals, usability issues, and user preferences, providing a comprehensive insight into the participants' experiences.

According to the findings, most participants from both groups found the AR experience to be very interesting and recognized its educational value. Users found the AR application to be simple, attractive, and easy to use, with one user from the "hybrid" group even testifying that "The digital content was so well registered on the physical object that there were moments they could not tell the difference between them." However, despite the increase in size of the scale model, a small number of users suggested that a bigger scale model would make the experience more engaging. Additionally, some users suggested that the digital content should be displayed in its natural size.

There were also some issues raised regarding the way the information was presented, the connection with the real world, and the association with the pictures provided. Users felt that too much information was presented, and they focused more on the experience they had on the mobile screen, neglecting to look around and connect the scale model with the 3D space around them. To address this, it may be helpful to incorporate more interactive elements that encourage users to move around and explore the space while interacting with the AR application. Users also suggested improvements regarding the interaction such as providing the option to enable subtitles, supplying additional information after zooming on tools, and showing the process through a more enriched character movement. These suggestions could help to improve the overall user experience and make the AR installation more engaging and interactive.

In summary, while users found the AR experience to be interesting and educational, there is room for improvement in terms of the connection with the real world, the association with the pictures provided, and the way the information is presented. Incorporating more interactive elements and addressing user feedback could help to create a more engaging and immersive AR experience. It is important to mention that the results showed that there were no significant differences in the overall performance of the two groups and we found no substantial differences that would suggest a significant divergence in their experiences. Based on the analysis of the think-aloud protocol, video recordings, handwritten notes, and comments in follow-up discussions, it can be concluded that both applications provided a similar user experience for both groups of participants.

7 Discussion

The results of the two studies indicate that the proposed approach of combining mobile AR content and physical scale model of the building is generally considered easy to use. All users, even those without previous experience in mobile AR, managed to follow the narration and observe the worker activities. No critical registration errors or mismatches have been reported, partially due to the stability of the augmented content on the scale model. The use of an open section of the building and the occlusion handling of digital content created an augmented experience that supported the required connection between intangible and architectural heritage and fostered exploration. Thus, there is possible merit in further exploring this paradigm and testing different configurations, sizes, and use cases. For example, a similar approach could be used at school before or after a visit to an archeological site or a historical settlement, giving students the opportunity to understand and admire the value of the place through the digital presentation of activities and rituals that took place in the past.

Following our observations from the studies, it seems that there is room for further improvement of the user interface and narrative aspects of the installation. The use of floating text annotating the content has been decided to enhance memory and learning, especially for new terms; however, for some users, this was ambiguous and confusing. Even though for the comparative study, the form of the labels has been redesigned, a minor confusion was still observed. It seems that some of the users wanted to have the ability to get more detailed descriptions of the content presented on the phone and they were treating the labels as buttons to get more info. Additionally, the request by some users to display subtitles for the narration is an indication that they recognized the importance of the content. On the other hand, there were users that were more interested in the visual part and wanted to have more detailed and higher quality graphics and animations. This confirms previous studies that there are different expectations about AR apps [42] and, thus, designers of future applications should consider a balance between visually appealing re-enactments and associated educational content. An interesting room for further study is to research effective ways to present the content across the digital and physical spaces and to create appropriate narrative supported through animation, audio, and textual annotations. There is a need for intuitive ways of controlling the presentation and accessing further information about elements of interest without distracting from the flow.

Content size and ergonomics are also important aspects that should be carefully taken into account to avoid user fatigue and discomfort. Some ergonomic requirements for handheld AR devices are provided in [54], but more most studies rarely include measurements about user posture and comfort. Accurate tracking of user movement is considered crucial for reducing motion sickness; hence, a good calibration system is essential for mobile AR applications. Additionally, the interface and interactions were considered simple and intuitive, reducing the likelihood of tiredness and discomfort during prolonged use. In both studies, the logging system showed that the average total duration of approximately 100–126 s was considered short term and within a comfortable timeframe for the users. Also, the average total path covered by users was approximately 3–5 m, which is considered a comfortable distance for interaction, and the average distance from the scale model was approximately 30–35 cm. We can conclude that users were less likely to experience fatigue and discomfort during use, due to the design of the application. Users had the ability to move their phone closer to the scale model and observe the content at the desired size, and this was also evident from the difference in the average distances between the two studies; still, it seems that the larger scale model contributed to a more positive experience. This is a finding that needs more thorough study. The fact that we logged and analyzed the phones' movement while using the app gave us a good insight on how our users approach the content. Similar techniques could be used to study more carefully the impact of the scene size and content duration on user satisfaction or discomfort.

What was evident from the first evaluation is that users would prefer a larger scale model. Although the size has been increased in the second study, there were still users asking for a bigger scene, and one of them would like to see the animations in the physical space. Even though some valuable insights came from the studies, further research is needed around these important aspects. Generally, the performance of an AR installation can be improved by following usability principles related to interaction between users and the application, error reduction and handling, the cognitive skills required by users, and the information provided to them [55].

In terms of enjoyment, it seems that the proposed approach generated a positive experience that could be enhanced with further interactive and playful elements. Generally, users considered the application interesting and pleasant, but some of them were expecting more in terms of graphics or interaction. These different degrees of perceived enjoyment that we noticed in our findings are attributed to the multiple levels of engagement that are commonly observed while people interact with installations [56]. Also, our results indicate that users seek to have fun and get engaged while interacting with mobile AR installations. The user's experience at cultural heritage sites includes factors related to the user (expectation, motivation, emotions) as well as how the user perceives, moves, and uses the natural space. During the interaction with an AR installation, the user's experience may be affected in a positive way by all these factors [57]. An interesting design challenge in this respect for similar applications is to include playful elements or challenges without disrupting the narrative elements that are necessary for the communication of ICH.

The results of the comparative study revealed some interesting findings about the effect of the 3D-printed scale model on user experience and learning. It seems that its presence did not affect the learning outcomes, as there was no significant difference between the learning gains in the two groups. Similarly, the spatial association was also not affected. There were also no significant differences in the way users approached the installation with their mobile phones. However, there was a noticeable increase in the hedonic aspects of the user experience, bringing the hybrid approach to the "desired" category. This is evidence that "phygital" approaches in cultural heritage may potentially increase user enjoyment and involvement. This might be especially important in museums and public installations to attract new users that might be reluctant to download and use a new app during their visit. It would be also interesting to research further approaches to enhance the material aspects of such installations, such as including tangible elements that contribute to the experience. For example, the user could move a physical element on the scale model and get, through her mobile phone, more information about the tools and activities in that location.

Finally, regarding the aspects of learning and spatial association, the results were mixed. On the one hand, there was an evident learning gain for both groups in the comparative study, showing that the AR experience contributed to learning about the leather tanning process for all participants. These results agree with relevant studies in the field of culture and indicate that users using AR applications accomplish better learning outcomes in cultural heritage. [58]. Our research also confirms previous studies that AR technology is considered realistic and direct, and when used properly, it can provide an experiential, enjoyable, informal learning experience [59, 60]. On the other hand, the results of the spatial association test were poor, indicating that the users could not easily relate the locations of the virtually reconstructed tannery scene to the actual building in its current form. This mismatch suggests that we should place more emphasis in introducing strong reference points in the scale model, allowing users to understand how the model maps the current building in an unambiguous way. The use of colors and selected landmarks could help towards this end. The lack of familiarity with the actual building among users could be another possible reason for the low scores. Due to the users' lack of familiarity with the building in its current form, it may have been challenging for them to accurately relate the locations of the virtual representation to the actual building. Finally, the virtual representation may have included ambiguous or difficult-to-interpret elements, which could have caused confusion and made it challenging for users to relate the virtual model to the actual building.

In summary, a scale model can provide a more comprehensive and holistic overview of a building with cultural value and its processes. Even though the augmentation on a scale model offers more control over movements, it is important to note that the proposed approach has its own strengths and weaknesses in addition to the augmentation of physical space. In terms of ergonomics, an augmentation on a scale model could be considered a better solution as movements are limited and users do not need to walk around interior spaces looking through a mobile device. Additionally, the ability to intervene in space according to the needs of the AR application can be an advantage. However, it is important to consider that the scale model approach may not be feasible for larger spaces or complex processes. On a technical level, occlusion and registration issues may affect the quality of the augmentation of physical space, but there are emerging technologies that can address these challenges. AR glasses may be expensive and unaffordable for most people at the moment, but advancements in technology could make them more accessible in the future [33]. Overall, it can be argued that utilizing augmentation on a scale model is a favorable choice for disseminating intangible cultural heritage, particularly for buildings with cultural value. This approach has the potential to significantly enhance visitors' experience and engagement with the site, by providing a more immersive and interactive way of experiencing the historical context and cultural significance of the building.

8 Conclusions

In this paper, we presented the design, development, and implementation of an AR installation for a former tanning factory, where the stages of the leather tanning process were re-enacted digitally on a scale model. The installation was placed in a renovated building, in which only some structures and machinery testify its former use. The main purpose of the experience was to communicate the history of the building and the ICH of leather tanning, in an enjoyable and educational way. An initial user evaluation of the installation led to positive results regarding this approach: it was considered easy to use, promoted learning about the tanning process, and was rated high in terms of user experience. In a follow-up comparative study regarding the effect of the scale model on the experience and learning, it was found that the hybrid physical-digital version did not impact learning and spatial association between the model and the actual building, compared to the purely digital one, but it increased the hedonic aspects of the user experience. Besides that, the study confirmed that in any of the two variations, there were clear learning gains. Our overall findings point towards some interesting directions for further research.

One area for further exploration is the appropriate size and content of the scale model used in the AR experience. This could involve testing different scales and types of content to determine what works best in terms of engaging users and effectively communicating the building's history and heritage. Achieving a deeper understanding of intangible and architectural heritage is also a crucial area for further investigation. This could involve exploring ways to incorporate more interactive and educational elements into the AR experience, such as audio guides or interactive games, to help users better appreciate the cultural and historical significance of the building. Looking ahead, the researchers plan to investigate the inclusion of playful and intuitive elements in the prototype. This could involve exploring ways to make the AR experience more engaging and fun for users, such as by incorporating elements of gamification or interactive storytelling. Finally, the researchers also plan to compare the proposed phygital AR approach with other relevant approaches for communicating intangible heritage, such as immersive VR (virtual reality). By comparing and contrasting different approaches, researchers can gain a more comprehensive understanding of the strengths and weaknesses of each and identify the most effective methods for communicating the history and heritage of buildings to a wider audience.

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Data availability Data will be made available on reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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