Gesture-Driven Storytelling

Designing interactive experiences for cultural heritage interpretation in blended spaces

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Storytelling has long been key to cultural heritage interpretation by encouraging participation and engagement. However, traditional methods often lack immersive qualities. The convergence of extended reality, interaction design, and storytelling offers transformative potential for cultural heritage interpretation in blended spaces. Most literature concerned with gesture-based interactions focuses on pre-defined gestures and user experiences. This study explores how gesture-driven storytelling supports interaction design for cultural heritage interpretation in blended spaces. A design workflow was developed to guide this process, comprising three stages: storyboarding, gesture coding, and prototype development. Here, storyboarding visualizes interaction concepts, gesture coding creates custom gestures, and prototype development integrates them in a creative coding environment. A pilot workshop was conducted where participants followed this workflow to create gesture-driven storytelling prototypes. Using prewritten code snippets, MediaPipe's pre-trained machine learning models for hand tracking, and a pre-coded Seljuk architectural ornament, participants developed interactive prototypes. Following the outcomes of this workshop, this study discusses the potential and challenges of gesture-driven storytelling for cultural heritage interpretation. This study contributes to human-computer interaction design and cultural heritage by demonstrating the potential of XR to transform cultural heritage interpretation and providing a reusable workflow that enables customized storytelling experiences.

Keywords: *Human-Computer Interaction, Gesture-Based Interaction Design, Storytelling, Blended Space, Cultural Heritage Interpretation.*

INTRODUCTION

Storytelling plays an essential role in preserving cultural heritage, conveying historical narratives, and fostering engagement (Okanovic et al. 2022; Petousi et al. 2022). Over the past few years, digital technologies have revolutionized storytelling, particularly in the context of cultural heritage interpretation, by allowing immersive and interactive experiences (Sylaiou and Dafiotis 2020; Skublewska-Paszkowska et al. 2022; Rizvic et al. 2024). In the literature, studies focusing on interactive digital storytelling for cultural heritage explore a range of methods, such as incorporating game design (Holloway-Attaway and Vipsjö 2020; Katsantonis et al. 2023), utilizing digital storyteller characters (O'Keefe and Benyon 2015), employing tangible interfaces (Chu and Mazalek 2019), and integrating natural gestures (Popovici et al. 2022). However, these studies generally prioritize and rely on predefined interactions with mainstream

gestures such as swipe, zoom in/out, and rotate (Caggianese et al. 2018; Lu et al. 2021; Li et al. 2022), which limit the potential for meaningful, user-driven engagement. While gesture-based interactions offer an embodied approach to interactive digital storytelling for heritage interpretation, they can also harness gestures as unique and dynamic tools for creative expression in narrative construction. From this point of view, this study aims to understand how gesture-driven storytelling can support interaction design for cultural heritage interpretation in blended spaces. Thus, this research proposes a design workflow that involves storyboarding, gesture coding, and prototype development to explore how gestures can act as narrative tools, shaping meaningful interactions with cultural heritage. A pilot workshop was conducted where participants followed this workflow to create gesture-driven storytelling prototypes, and the study provides insights into the narrative potential and challenges of gesture-based interaction design for cultural heritage interpretation based on the workshop outcomes.

RELATED WORK

Gesture-driven storytelling combines interaction design, digital storytelling, computer vision, and extended realities to provide new ways to engage and communicate with cultural heritage. This section presents the conceptual framework of the study by exploring the related literature on digital storytelling, gesture-based interaction design, and blended spaces in cultural heritage.

Digital storytelling and gesture-based interaction design

Rooted in oral traditions and later adapted to print and audiovisual media, storytelling has evolved in response to technological developments. In this regard, digital storytelling has emerged in cultural heritage studies as a way to convey stories about artifacts, people, and historical places through various digital media such as images, video, text, audio, animation, and interactive elements (Carrozzino et al. 2018; Psomadaki et al. 2019; Petousi et al. 2022; Rizvic et al. 2024). In digital media, stories are no longer passive but are dynamically shaped by user interaction, allowing for more embodied and participatory experiences (Shin 2018). A notable advancement in this shift is the use of gesture-based interaction, enabling users to interact by using body movements rather than the usual input methods using touchscreens or keyboards.

By emphasizing that meaning-making and knowledge are deeply associated with bodily actions, gesture-based interactions build on the principles of embodied cognition (Klemmer et al. 2006; Flynn 2013). This viewpoint suggests that cognition emerges from the dynamic relationship between the body, media/environment, and digital interfaces, rather than being limited to the mind. As people physically engage with interactive media, the sensory experience and movement shape their understanding, and meaning is co-constructed in gesture-based interactions. In digital storytelling, gestures act not only as commands, but also as expressive actions that shape the user engagement and narrative structures. They provide embodied and seamless ways to navigate, control, manipulate, and interact with the virtual environments. In cultural heritage applications, gesture-based interactions are recognized as a more intuitive way for visitors to interact with historical narratives and artifacts. Gesture-driven interaction has been shown to improve learning outcomes and emotional engagement with heritage content in museum installations (Li et al. 2022; Katsantonis et al. 2023; Heng et al. 2024). Yet, most existing research focuses on the design, development, evaluation, and user experience of interactive media in cultural heritage contexts by utilizing predefined gestures. Here, predefined gestures are a collection of body or hand movements that are specifically programmed to correspond with particular commands or

responses in interactive systems. These gestures include mainstream gestures that are commonly accustomed in today's society, as well as peculiar gestures that are predefined to perform case-specific actions. Most studies utilize mainstream gestures such as grab, rotate, zoom in, zoom out (Caggianese et al. 2018), thumbs up (like), thumbs down (dislike), swipe, point (Baraldi et al. 2015), raise left/right hand (Spallazzo and Ceconello 2018; Li et al. 2022), and standardized gestures provided by the device systems such as HoloLens (Bekele 2019; Giariskanis et al. 2022). Various studies use peculiar gestures such as cultural dance movements (Reshma et al. 2023), bare-hand movements of craftsmen (Manitsaris et al. 2014; Koutsabasis and Vosinakis 2018), and artistic gestures in traditional and ancient arts (Zhang and Dong 2018; Heng et al. 2024). The literature either focuses on conveying cultural heritage narratives in the form of interactive media or approaches gestures themselves as a cultural heritage context to be interpreted and communicated through interactive media. Yet, while focusing heavily on how users adapt to predefined gestures, studies neglect that gestures themselves can emerge from the narrative and interaction process. This reliance on predefined gestures limits the potential for gestures to evolve into dynamic, user-driven tools for narrative construction and creative expression. Therefore, this study seeks to approach gesture-based interaction in digital storytelling as a creative and interpretative act, rather than a mere functional command.

Blended spaces for cultural heritage interpretation

Particularly with the emergence of extended reality (XR) technologies, encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR), the concept of blended space has gained traction in cultural heritage interpretation practices. Here, blended spaces refer to hybrid environments in which virtual and physical elements blend seamlessly, facilitating novel modes of interaction and fostering multi-sensory experiences (Benyon 2012, 2014; Cools et al. 2022; Resmini et al. 2023). In the context of cultural heritage, XR technologies transform passive heritage experiences into immersive and participatory interactions (Psomadaki et al. 2019; Petousi et al. 2022). These technologies enable users to engage with historical sites, artifacts, and narratives through embodied interactions that strengthen their appreciation, knowledge, and emotional connections with the heritage content (Shin 2018; Katsantonis et al. 2023).

One of the main affordances of blended spaces in cultural heritage is their ability to recreate historical settings, visualize inaccessible or lost artifacts, and provide interactive digital storytelling experiences (Skublewska-Paszkowska et al. 2022; Duranti et al. 2024; Rizvic et al. 2024). For instance, Olaz et al. (2022) employed 3D projection mapping techniques to overlay historical images onto the physical environment, allowing visitors to experience the transformation of the site over time as part of an interactive digital storytelling experience. Similarly, various MR applications have been developed to superimpose virtual elements onto physical spaces, providing users with interactive experiences and contextualized insights into cultural heritage, including historical events, craftsmanship, and everyday life (Koutsabasis and Vosinakis 2018; Liestoel 2019). Some existing studies implement user inputs via touchscreen or controller-based interactions (Panopoulou et al. 2018; Okanovic et al. 2022), which can limit engagement and disrupt immersion. A major challenge in designing interactive experiences for cultural heritage interpretation in blended spaces includes developing simple, intuitive, meaningful, and easy-to-use interaction methods. In this regard, gesture-based interactions offer more natural and intuitive means of engaging with multimedia heritage content through bodily and bare-hand movements (Popovici et al. 2022;

Neamțu et al. 2024). Most studies exploring natural interactions use motion-sensing devices such as Leap Motion (Caggianese et al. 2018; Koutsabasis and Vosinakis 2018; Zhang and Dong 2018; Heng et al. 2024; Neamțu et al. 2024), Kinect (Pietroni et al. 2012; Li et al. 2022), and HoloLens (Bekele 2019; Hammady et al. 2021) to detect, recognize, and interpret user gestures in blended spaces. In terms of presentation techniques, visual outputs of interactive systems are often presented through screen- or projection-based installations (Heng et al. 2024; Panopoulou et al. 2018; Spallazzo and Ceconello 2018) and wearable devices like HoloLens, head-mounted displays, or VR headsets (Bekele 2019; Kyriakou and Hermon 2019; Hammady et al. 2021; Giariskanis et al. 2022; Pedersen et al. 2024). However, as noted above, despite the potential of blended spaces to facilitate user-driven interactions, most current systems are based on predefined gestures that serve as functional commands rather than expressive storytelling tools and limit the emergence of more dynamic and narrative-rich participation by imposing structured interactions.

METHODOLOGY

This study explores how gesture-driven storytelling can support interaction design for cultural heritage interpretation in blended spaces. To do so, a design workflow was developed to guide this process, consisting of three stages: storyboarding, gesture coding, and prototype development. This workflow aims to provide a structured yet flexible approach that enables designers/participants to create interactive storytelling experiences using their own custom gestures, going beyond the predefined, mainstream gestures.

In the literature, Rizvic et al. (2017) introduced a design workflow and guidelines for interactive digital storytelling in cultural heritage, utilizing XR technologies. Their design workflow included three stages: preproduction, which defined the scenario and visual styling as well as production planning activities; production, which involved asset creation and interactive virtual environment development based on the scenario and storyboard; and postproduction, which assessed the application's immersion and edutainment levels to refine, edit, and finalize the interactive digital storytelling concept (Rizvic et al. 2017, pp. 258-259). While this design workflow has been applied in various XR projects (see Okanovic et al. 2022; Rizvic et al. 2022, 2024), these projects have involved large multidisciplinary design teams that included scenarists, actors, directors, engineers, psychologists, designers, and so on. Unlike these large-scale productions, this study focuses on a more designer-centric and accessible approach, where an individual designer/participant follows the design workflow, combining storyboarding, gesture coding, and prototype development. Furthermore, since existing studies tend to treat gestures more as functional tools, this study does not impose predefined or standardized gestures. Instead, it allows designers to define and customize their own gestures by keeping in consideration narrative, heritage context, and user experience expectations. The proposed design workflow consists of three stages:

1. **Storyboarding:** Creating a storyboard to visualize gesture-based interaction scenarios. The storyboard outlines how gestures are intended to interact with the visual elements of a cultural heritage context.
2. **Gesture coding:** Translating user-defined gestures from storyboards into functional gestures; experimenting with hand tracking, gesture recognition, and responsiveness.
3. **Prototype development:** Finalizing the code of the functional prototype; debugging, testing, and refining interactive experiences.

A pilot workshop was conducted with three participants to evaluate and revise this workflow structure. Each participant was provided with the

necessary tools and resources to create gesture-based interaction designs. These tools and resources included MediaPipe's pre-trained machine learning models for palm detection and hand landmarks, the p5.js coding environment, TensorFlow.js and ml5.js libraries, pre-written code snippets, and pre-coded visuals. MediaPipe is an open-source, cross-platform framework developed by Google to facilitate the use of machine learning models for recognition-focused tasks (Zhang et al. 2020). By utilizing MediaPipe, multiple hands can be recognized and tracked simultaneously, with each hand represented by 21 hand keypoints/landmarks on the palm and finger joints. Different combinations of these keypoints were used by the participants to design gesture-based interactions, along with the help of prewritten code snippets. For the cultural heritage context, the workshop focused on architectural ornamentation motifs from the Seljuk period. Agzikara Han, a 13th-century caravanserai in Turkey, was selected for its rich Seljuk architectural heritage and intricate ornamental motifs, making it a strong case study for exploring gesture-driven storytelling in cultural heritage (Figure 1). A circular Seljuk ornamental motif from Agzikara Han was provided as a pre-coded pattern (Figure 2; geometry obtained from Önkol Ertunç and Yaman 2019), in which parameters of the shape served as interactive elements that could be manipulated through hand gestures.

PILOT WORKSHOP AND FINDINGS

The pilot workshop was designed to revise the proposed workflow and explore the technical and creative possibilities of gesture-driven storytelling for cultural heritage interpretation. Participants were encouraged to approach the design task with conceptual flexibility, which allowed them to delve into functional and aesthetic aspects of the provided geometry by leveraging the capabilities of MediaPipe's pretrained models and JavaScript coding environment p5.js.

Participants were first introduced to related computer vision technologies, XR examples, the proposed workflow, and heritage context; then, they were asked to individually design gesture-based interactions with the provided tools and resources. Each participant approached the design task from a unique perspective, shaping their interactions around different functional and conceptual interpretations of their custom hand gestures (Table 1). While storyboarding helped them in mapping out how and which hand movements would engage with the pre-coded Seljuk motif, the coding sessions presented various creative and technical challenges.

Participant A focused on spatial manipulation, treating the motif as a responsive virtual artifact that could be revealed, moved, scaled, and rotated via hand gestures. An open-palm hover revealed the motif, resembling an act of discovery and pinch/stretch gestures controlled its size.

Figure 1
(left) Agzikara Han in Aksaray, Turkey (Deniz 2007); (right) Ornamental details (Eravşar 2017)

A circular palm motion moved it across the screen. Hand rotation around the z-axis adjusted the orientation, allowing for a wheel-like animation (Figure 3). This interaction aligned with conventional digital storytelling techniques in which artifacts emerge as a narrative development and provide a sense of physical control over the virtual object. Here, the main challenge was to ensure smooth transitions between different gesture states. The sensitivity of gesture recognition sometimes resulted in unintended activations; thus, it required threshold adjustments to improve accuracy.

Participant B took a generative approach and aimed to create dynamic visual compositions through gestures rather than simply modifying an object. The motif, existing initially on the screen, was diffused with an open-palm hover. As it created traces of the same pattern, users could use hand movement and pinch/stretch to dynamically scale and reposition it. Rotating the hand while stretching duplicated and multiplied the pattern, emphasizing its generative potential (Figure 3). This tactic evolved the interaction into an active drawing process in which gestures kept shaping a continuously changing composition. Lastly, a closed palm gesture resets this diffusion and multiplication process, allowing users to restart the pattern generation. This design presented some challenges in balancing gesture responsiveness with artistic intentions. The participant experienced that gesture detection delays occasionally disrupted the fluidity of pattern generation, which called for parameter tuning to improve real-time responsiveness.

Participant C approached the motif as a reactive, living entity that responds to gestures expressively. An open-palm hover was used as an awakening gesture, triggering the motif to glow and vibrate, representing its historical significance and energy. Closing the palm (or making a fist) calmed the motif, returning it to a dormant state. A circular index finger motion morphed the motif into different historical ornaments, allowing users

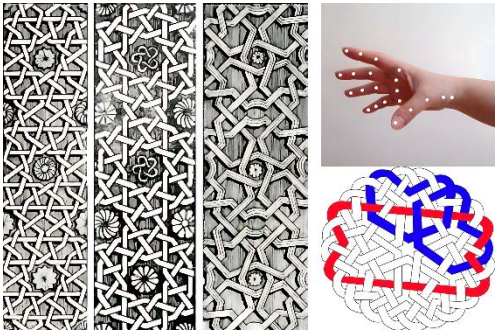

Figure 2
(left) Erdmann's drawings (1961); (right top) hand landmarks; (right bottom) pre-coded pattern, red and blue indicate repeating loops in the knot

Participant	Key gestures
Participant A	*Open-palm hover:* Reveals the motif on the screen *Pinch/Stretch:* Shrinks/expands the motif *Circular palm motion:* Moves the motif across the screen *Rotate hand:* Rotates the motif around the z-axis
Participant B	*Open-palm hover:* Diffuses the motif, creates pattern traces. *Pinch/Stretch:* Shrinks/expands the motif *Move while Pinching or Stretching:* Moves the motif across the screen leaves diffused pattern traces *Rotate 90° while Stretching:* Duplicates and multiplies the motif *Closed-palm:* Resets the pattern diffusion and traces
Participant C	*Open-palm hover:* Awakens the motif, glowing and vibrating *Closed-palm:* Calms the motif, stops the movement *Circular index finger motion:* Morphs the motif into different historical ornaments *Pinch/Stretch:* Shrinks/expands the motif

Table 1
Key gestures from the participants' storyboards

to explore changes over time. Pinch and stretch gestures were used for resizing. Here, the challenge was to deal with the gesture ambiguity between circular index finger motion and stretch gesture (index and thumb extended). As both gestures involved extended fingers, it led to unintended activations.

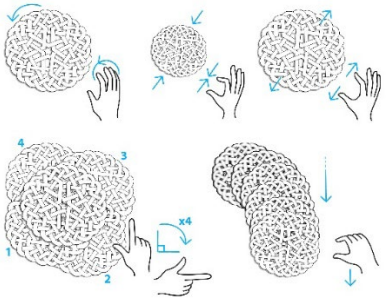

Figure 3
Example gestures: (top left) rotate hand; (top middle) pinch; (top right) stretch; (bottom left) rotate 90° while stretching; (bottom right) move while pinching or stretching

Not surprisingly, all participants used the same pinch/stretch gesture to resize the motif (see Figure 3), which is a very common gesture used in touchscreens and interactive systems. In the context of gesture-driven storytelling for heritage interpretation, its overuse may limit the expressiveness of the interactions, although its familiarity seems to help reduce the cognitive load for participants. The conventional nature of this gesture, therefore, raises the question of how standard mainstream gestures can be extended or reinterpreted to create more narratively rich and culturally meaningful interactions in digital storytelling. In addition, the pilot workshop provided several insights into gesture-driven storytelling for cultural heritage interpretation. Participants encountered challenges in translating their storyboarded concepts into prototypes, particularly due to conflicting gestures. The overlap in gesture parameters made it difficult to maintain gesture accuracy and interfered with the seamless execution of interactions. A major challenge was to consider the parameters of each gesture more holistically to keep them as distinct as possible while avoiding unintentional overlap. Multimodal feedback, including motion-based and visual cues, played an important role in enhancing participant engagement. Responses to gestures, such as glowing, moving, vibrating, etc., stimulated interest in creating interactive experiences. Another issue was the technical complexities of the system setup. Although the participants had proficiency in coding and prior knowledge regarding machine learning models, further documentation, clearer instructions, and diversified examples showcasing how to adapt the prewritten code snippets and accommodate hand landmarks would be beneficial to improve the proposed workflow. Finally, the workshop outcomes highlighted the expressive and narrative potential of gesture-driven storytelling, demonstrating how hand gestures can influence and shape cultural heritage interpretation.

CONCLUSION

This study aimed to understand how gesture-driven storytelling can support interaction design for cultural heritage interpretation in blended spaces. Through a pilot workshop implementing the proposed design workflow, we explored how gestures can act not only as functional commands but also as expressive tools for narration. In this regard, this study emphasizes the importance of moving beyond predefined gestures and adopting gesture-based interaction as a dynamic, user-driven storytelling instrument in cultural heritage applications.

Future research will address gesture conflicts by improving gesture differentiation through multimodal inputs, adaptive thresholding, or temporal variations. The reliance on mainstream gestures like pinch/stretch highlights the need to investigate alternative interaction metaphors inspired by historical and embodied storytelling traditions. Furthermore, expanding the study to include a larger participant pool and diverse heritage contexts will help in the better evaluation and refinement of the proposed workflow. To reduce technical challenges, future studies will include further documentation, structured

instructional materials, and guided examples for adapting gesture mappings. Additionally, looking into collaborative scenarios in shared narrative spaces, such as immersive mixed-reality settings, could broaden the scope of gesture-driven storytelling.

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