# Volumetric Video in Augmented Reality Applications for Museological Narratives: A user study for the Long Room in the Library of Trinity College Dublin

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Cross-reality (XR) technologies are quickly establishing themselves as commonplace platforms for presenting objects of historical, scientific, artistic, and cultural interest to the public. In this space, augmented reality (AR) is notably successful in delivering cultural heritage (CH) applications, including architectural and environmental heritage reconstruction, exhibition data management and representation, storytelling, and exhibition curation. Generally, it has been observed that the nature of information delivery in applications created for narrating exhibitions tends to be informative and formal. Here we report on the assessment of a pilot scene for a prototype AR application that attempts to break this mold by employing a humorous and playful mode of communication. This bespoke AR experience harnessed the cutting-edge live-action capture technique of volumetric video (VV) to create a digital tour-guide that playfully embellished the museological experience of the museum visitors. This applied research paper consists of measuring, presenting, and discussing the appeal, interest, and ease of use of this ludic AR storytelling strategy mediated via AR technology in a CH context.

CCS Concepts: • **Computing methodologies** → **Mixed / augmented reality**; • **General and reference** → *Validation*; • **Applied computing** → Arts and humanities.

Additional Key Words and Phrases: Mixed reality, augmented reality, user study, museology, cultural heritage, ludic interfaces, playfulness.

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## 1 INTRODUCTION

There is a rich, expanding contemporary movement towards using immersive cross-reality (XR) technologies – a collective term for augmented, virtual, and other mixed-reality (MR) platforms – to provide multimodal CH experiences, through various combinations of the physical and digital worlds (Bekele et al. 2018). These types of practices are broadly applied to embellish visitor experiences of CH sites. The recent emergence of increasingly complex immersive XR technologies, whose sophistications increase in correlation to the miniaturization and portability of hardware, and the exponential evolution of computing power, make this technology an ideal fit for

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Fig. 1. The Long Room within the Old Library in Trinity College Dublin. Photograph by David Iliff. License: CC BY-SA 4.0, via Wikimedia Commons. (https://commons.wikimedia.org/wiki/File:Long_Room_Interior,_Trinity_College_Dublin,_Ireland_-_Diliff.jpg).

CH applications. These factors combine to facilitate the co-emergence of increasingly rich AR experiences in a domain that is quickly maturing.

This paper reports on the assessment of a pilot study for an AR application, built-in collaboration with The Library of Trinity College Dublin. The Old Library and the Book of Kells are located in the heart of Dublin City and The Book of Kells is a UNESCO Memory of the World item. The AR application harnesses cutting-edge volumetric video (VV) capture techniques and proposes innovative curatorial storytelling techniques based on humor and playfulness. The goal was to measure the appeal of using such a communication strategy in an AR museum guide application. Featuring a live-action portrayal of Dean Jonathan Swift sheepishly recalling an embarrassing biographical anecdote from his student days at Trinity, the application was developed to make the museum's content more light-hearted and accessible.

The Library of Trinity College Dublin curators were interested in using MR to enhance the overall experience, but they held the view that any digital intervention should not attempt to supplant the will of tourists to experience the site in person. Embodied visitors constitute a crucial funding model that sustains the cost of managing and preserving this CH site, hence the strong argument for pursuing the site-specific, AR format of user engagement. As a real-time engagement paradigm, AR is characterized by its perceptual alignment and anchoring of virtual objects and digital information to real, tangible space (Azuma 1997). This first stage of the project was to develop a prototype AR scene and measure its appeal by surveying potential users. Positive feedback may predicate its expansion to a multi-scene, location-based narrative, where visitors would explore the Long Room, discovering AR scenes "that help draw their attention to the multitude of historical, architectural and archival details, procuring a deeper, more enriching experience of the world heritage site" (O'Dwyer et al. 2018, p. 349).

In addition to books and manuscripts, the Library of Trinity College Dublin's collection consists of visual art sculptures and artefactual national treasures. The library's staff noted that the marble busts of famous scholarly figures that line the central aisle pique the visitors' attention, see Figure 1. Therefore, it was agreed that, for the prototype, we would tap into the visitors' curiosity by developing an AR application that features the appearance of a digital-virtual persona beside its corresponding sculpture. The prototype scene would, therefore, consist of a one-minute linear narrative featuring a simulation of Jonathan Swift imparting "a whimsical, idiosyncratic anecdote linked to the Long Room and its context" (O'Dwyer et al. 2018). For this purpose, an actor performing as Jonathan Swift was recorded using the state-of-the-art 3-Dimensional (3D) live-action recording technique of VV. As a new form of visual representation, it enables users to view live-action video content as a 3D volume and to view it from any chosen viewpoint (Pagés et al. 2018). As such, it is highly suitable for AR applications targeting

a more natural, conversational depiction. The decision to pursue a playful approach to the narrative was based on observations from the library staff, who reflected that many visitors exhibit symptoms of information overload, often overlooking the details of aesthetic and historical significance. It was felt that a friendly AR tour-guide could help draw the focus of visitors' attention to objects of interest within the museum space. Therefore, our formative goals were sketched to assess 1) the appeal of volumetric video, which was felt to be friendlier and more familiar than other forms of multimedia, and 2) how humorous narrative disclosure in a CH context generally contributes to the enrichment of informal learning environments (ILEs).

This manuscript details the pilot study that explored the merits and pitfalls of humorous, playful, technology-driven forms of curatorial storytelling in an ILE and reports on the emergent qualities of analysis that were of significant interest in the use of VV for CH, extending our earlier prototype application (O'Dwyer et al. 2018). This research seeks to improve upon the design of future studies by raising issues of functionality, usability, and user experience that are of particular interest to the computing and cultural heritage community. For this purpose, three hypotheses were developed:

- H1: The use of VV in CH oriented AR applications raises specific areas of interest for information communication in museological contexts
- H2: Humorous, playful anecdotes potentially represent appropriate vehicles for curatorial information disclosure and should be explored further within particular CH use cases
- H3: The combined effects of H1 and H2 present an appealing format for AR museum guides that deserves further development and investment in CH application evaluations

To this end, we assess both quantitative and qualitative preliminary data gathered in a pilot user study on a CH focused VV application from a selection of university visitors, staff, and students. The main motivations for this pilot assessment were to identify user needs and requirements for further scientific research of VV in CH oriented AR applications, and generate research questions that inform future in-depth studies concerning specific areas of computing and cultural heritage.

## 2 BACKGROUND & RELATED PROJECTS

Since the 1990s, scholars have advocated the potential for AR approaches to CH, in terms of both visualization and aiding scholarly understanding, data acquisition, preservation, and communication (Brogni et al. 1999). Since then, a consistent rise in the adoption of AR in the CH sector has been realized, a trend predicted to continue given the appropriateness of the technology to museological demands (Arcese, Di Pietro, and Guglielmetti 2011). Bekele et al. (2018) harness this position as a justification for their comprehensive survey of the field, endeavoring to collate and analyze current research literature, review previous challenges, and predict future directions based on their observations. They maintain that several innovative, interactive digital solutions aimed at enhancing users' perceptions of art have emerged, albeit with varying degrees of success, and that a plethora of new applications remains undiscovered. Use-cases that employ AR in CH contexts include architectural or environmental reconstruction, exhibition data management, and curation and storytelling.

### 2.1 Architectural and environmental heritage reconstruction using AR

The scope of many architectural and environmental heritage reconstruction projects is to convey a known earlier state of a CH site, via digital reconstructions. These experiences often seek to visualize the architecture of historic ruins, presenting them as they would have appeared during a civilization's prosperity (Vlahakis et al. 2002). Such AR experiences are usually delivered via mobile phones or tablets and superimpose pictorial representations onto current views of the heritage sites (Okura et al. 2015; Zoellner et al. 2009). Alternative approaches to this field include developing 3D reconstructions of CH buildings and artifacts and displaying them via a collective, interactive, immersive multimodal virtual environments Han et al. (2019); Oliva et al. (2015). Chrysanthi et al.

(2013) developed an innovative project that harnessed the user's gestures by combining the tangible interface of a book, embedded AR markers, and visualization techniques.

## 2.2 Exhibition data management and representation using AR

Museums require cost-effective platforms for virtually representing their archives. A selection of AR projects has emerged that provide interactive visualizations that are suitable for both museum curators and the public. While exhibition data management is mainly for organizational purposes, it is still pertinent to curation – the selection of cultural heritage data and its representation for the end-user. Prototypical examples can be seen in *The Loupe* (Damala et al. 2016) and *Reanimating Cultural Heritage* (Rattanarungrot et al. 2014). Other examples employ 3D reconstruction techniques to display simulations of cultural artifacts using marker-based interaction techniques (Liarokapis 2007). MR experiments have also been shown to enhance interpersonal interaction in public places, exhibitions, galleries, and museums (Hall et al. 2001). In this context, Naemura et al. (2010) explored various digital display systems for superimposing 3D virtual content onto physical exhibits without the use of HMDs. Similarly, Benko et al. (2004) focused their research on a combination of technologies (HMDs, multi-touch interfaces, large screen displays, laser scanners, handheld displays, etc.) to allow multiple users to simultaneously interact with archaeological sites.

## 2.3 Storytelling and exhibition curation using AR

Storytelling and exhibition curation is the most pertinent use-case for VV in CH applications. Curation describes a method of presenting a subset of a cultural institution's content to communicate a story or perspective. Many museums and galleries have too much content for short-term visitors to absorb in a short space of time, therefore, curators organize a subset of the collection into a story that is digestible and memorable. However, these stories are often told formally and matter-of-factly, lacking innovation or zealous enthusiasm. Telling stories is one of the things humans are best at, yet, in formal and informal educational settings, institutions often fall into the trap of monotonously listing-off factual details and dates in a wholly forgetful way.

AR storytelling strategies can be summarized into three succinct categories: reinforcing, reskinning, and remembering (Azuma 2016). Reinforcing describes a storytelling strategy that is used in locations that are already inherently interesting, and the AR representations embellish an existing cultural intrigue by forming "a new type of experience that is more compelling than either the virtual content or reality by themselves" (Azuma 2016). This includes the reinstatement of objects, scenes, sets, and characters that are relevant to the site, but which may have become depleted or lost over time. This is analogous to the architectural reconstruction strategy. Reskinning is a strategy for reinventing a space to suit the story being told. It is not location-specific and is, therefore, more suited to fictional AR stories and games, not CH. Remembering is particularly pertinent to this study, as it entails a process of drawing out memories and retelling stories at site-specific locations. Combining personalized stories and memories with the sensation of being physically present can evoke an experience that is more powerful than either the location or virtual content viewed in isolation (Azuma 2016).

Papagiannakis et al. (2005) presents an early example of a 3D exhibition that superimposed 3D virtual animated characters and flora onto the real-world view using an HMD, and Kim et al. (2009) developed an application for realistically positioning virtual characters, re-enacting historic life, within physical scenes. Lombardo and Damiano (2012) presents a CH storytelling-based application for a mobile device featuring "an anthropomorphic guide". They consider the unique context, user interaction issues, and logistical issues posed by the mobile device. XR technologies have also been used in combination with real-time mediation techniques to create "aesthetic, dramaturgical, and emotional" narrative experiences (Magnenat-Thalmann and Papagiannakis 2005), and with 360 "still and video panoramas", using "a combination of computer graphics and 3D modeling", to explore the potential of interactive storytelling (Kwiatek and Woolner 2009). Dow et al. (2005) developed a mobile handset

"audio-based dramatic experience" in which voice actors impersonated deceased residents of a cemetery, telling stories from their lifetimes, while a meta-narrative guided visitors to the relevant grave-sites. Importantly, none of these existing projects use VV technology, which makes our application of it for CH storytelling and curation novel and innovative.

### 2.4 AR device comparison studies

Vainstein et al. (2016) discussed differences between museum audio guides and HMDs. This research highlighted that, firstly, current audiovisual museum visitor guides "force the visitor to hold the guide and to look at its screen", which is detaching from the overall museum experience, and secondly, audio-only guides do not provide as many additional enhancements to the museum experience. This raises questions about how these differences can be balanced to positively affect the museum visitor's experience.

HMDs and hand-held devices are becoming popular for AR applications in CH, yet platform comparison studies are rare (Bekele et al. 2018). Among the most useful studies that directly compare hands-free devices and hand-held devices in CH contexts are: Greenfeld et al. (2018) who compared five different MR devices, concluding that tablet devices were either equal to or better than HMDs; Riedlinger et al. (2019) who observed users collaboratively engaging with indoor AR visualizations using HMDs and hand-held devices, and compared them from interactive collaboration and building information modeling perspectives, and the participants found both devices comfortable, noting that the HMD was more immersive but the tablet was easier to interact with; Baber et al. (2001) who compared helper technologies on an HMD, a personal digital assistant, and a tablet in an art gallery, and evaluated their effects on information retention; and Vlahakis et al. (2002) who reported on an AR system using a laptop with an HMD, a pen-PC, and a palmtop computer, which was the preferred device due to its compactness and lightweight design.

## 3 A VOLUMETRIC VIDEO AR APP FOR THE LONG ROOM: A USE-CASE

Informal learning environments (ILEs) – public historical, cultural, and scientific institutions – are widely acknowledged as valuable spaces for the further education of persons of all ages and cultural backgrounds (Falk 1999; Falk and Dierking 1995). Although ILEs do not demand the rigorous concentration levels associated with formal learning environments, factual CH content can often be highly detailed and somewhat dry. Although they are "nonlinear, self-paced, voluntary, and exploratory" (Screven 1986, p. 109), ILEs can be tiring to concentrate in for long periods; therefore, a significant drop-off in attention is to be expected. This is particularly true for large exhibition spaces, where there is no possibility for a rest-break between main sections of an exhibition, and fatigue can be exacerbated if individuals are not accustomed to reading large amounts of historical, factual, biographical, and specialized details.

The library curators and staff observed that many visitors pass through the Long Room in a trance, overlooking the temporary, curated exhibitions, and the multitude of permanent artefactual exhibits. It was suggested this could be the result of the building's breath-taking architecture, or it could be symptomatic of the quintessential tourist experience of being anonymized, herded through an exhibition, and over-loaded with information. Before entering the Long Room proper (on the first floor), visitors engage with detailed explanations of early Christian manuscript illumination (on the ground floor). Fully engaging with the literature and audio-visuals in the manuscript exhibition takes about 45–60 minutes to complete. Exhibition visitors then move directly upstairs to the Long Room, to visit the architectural heritage section. Staff believed the reason for flagging attention levels is because there is no opportunity for visitors to take a break between exhibition sections.

In an age where tourists are influenced by grassroots, user-driven rating platforms, the prevalence of disparaging reviews purporting that the exhibition's content is mediocre, boring or uninteresting could be detrimental to the footfall-based business model, which ensures the preservation and management of the architectural heritage and

priceless collections. The museological problem consists in drawing the visitors' back to a state of attentiveness and openness to learning more detail, ultimately offering a richer visitor experience. It was, therefore, suggested that a technology-based intervention at this stage of the tour could furnish this objective.

While many CH AR projects tap into acclaimed scholarly discourse, they also present an approach to storytelling that is conventional. Contrary to prevailing formats, the presented project uses innovative humorous and playful modes of information disclosure. However, it is not a fully developed AR tour-guide application for engaging numerous exhibits; it is a single prototype scene designed for one specific museum exhibit. It aims to refocus visitor attention on the museum space by building empathy and amiability with its users. The user study assesses the appeal and demand for such an application in the Long Room context.

The task of conveying museological information humorously and playfully is complex. Small, naturalistic changes in bodily gestures and facial expressions greatly contribute to a viewer's interpretation of the content and their perception of listening to a believable human. Even though 3D virtual animated characters can be used for AR CH applications (Papagiannakis et al. 2005), depicting a more realistic human character improves the suspension of disbelief; 3D computer-generated (cartoonish) characters, are often perceived as uncanny, and "affinity towards virtual characters is a complex interaction between the character's appearance and personality" (Zibrek et al. 2018). Thus, to preserve human realism and to integrate the nuanced tones of a humorous delivery, the state-of-the-art live-action capturing technology of VV was used.

## 4 TECHNICAL DESCRIPTION

In this study, we use a prototype application that was developed in an earlier work (O'Dwyer et al. 2018). Extending this earlier work, we *(i)* assess different quantitative and qualitative assessment techniques for similar future CH oriented AR studies, *(ii)* conduct a pilot study in the Long Room of the Old Library at Trinity College Dublin using two different AR devices, and *(iii)* raise questions that would be relevant for future studies on functionality, usability, and user experience.

The application of VV in this study targetted the library's historic content in a way that was engaging for contemporary museum visitors by having them engage with a realistic 3D representation of a historical personality; one who acts as a tour guide and is viewed via an HMD or a tablet. An actor was, therefore, recorded using a VV technique involving the capture of live-action simultaneously across multiple video cameras (in this case 12). The cameras were strategically placed, in a 360-degree arc and the performance was recorded in a green-screen studio, which surrounded the actor in three-dimensions. This method simplified the segmentation (or chroma-keying) processes at the postproduction stage.

The process of volumetric capture follows the underlying principles of photogrammetry (the process of recording, measuring, and interpreting photographic images), creating a 3D volumetric, textured model for each frame of video. At the playback stage, the software iterates through these models at the standard video frame-rate of 30fps, thereby creating the illusion of movement in the same way as conventional film. The individual videos had to be synchronized, as each was comprised of the same number of frames so that the gesticulations captured on one camera exactly matched the same frame number on any other given camera. Analogously, the audio was recorded separately but concurrently in high resolution using a high-quality Sennheiser radio microphone, matching the video files' length and playback speed. As is observed in other video practices, viewers are particularly sensitive to audiovisual misalignment issues; which is most apparent in lip-synching or dialogue overdubbing where speech is used. After the individual camera clips were trimmed and aligned, the human figure was then segmented – "to separate the dynamic foreground from the static background", (Pagés et al. 2018) and a thresholded silhouette was generated for each frame of video. Then the footage was exported as 1) a series of images and 2) a series of silhouettes that correspond to each frame (O'Dwyer et al. 2017).

The pipeline for generating the 3D volumes is based on a combination of two-volume estimation techniques, as such: 1) "a novel, multi-source shape-from-silhouette (MS-SfS) approach", which mobilizes the silhouettes, the 3D skeleton and color consistency to generate a 3D volume, and 2) multi-view stereo (MVS), which is used to generate a dense 3D point cloud (Pagés et al. 2018). The resulting data are, therefore, merged using a fusion technique that generates complete and accurate 3D models, each textured using a multi-view technique that combines all input images to form a photorealistic 3D model. A separate 3D model is then generated for each frame of the video. A sample video can be seen on the project webpage[1].

The VV assets were then imported into the Unity game engine using a custom-built SDK that dynamically loads, displays, and then removes the textured models (that constitute the VV) at runtime. The interactive functionality implemented for this pilot scene consisted of basic play, stop, and restart functions and some basic hand gestures for positioning and resizing the character in its context. Spatial tracking was taken care of by the built-in APIs of each AR device. That is, the simultaneous localization and mapping in real-time, which are necessary operation for tracking, are handled by the ARKit algorithms for the iPad, and the "spatial mapping" feature of HoloLens, which generates an environment mesh in real-time for localization and tracking. The scenes were then loaded directly on to each of the AR platforms. As an AR application, the user's visual link with the real world was maintained, and the images of the characters were superimposed on to their vision using the "see-through" AR paradigm (where the user views reality through optical elements). Both platforms used the same VV assets, and the two applications are identical except for the experience of watching them on each platform.

Although VV technology allows us to capture and display humans with high fidelity, it has its limitations. In its current form, VV is closer to a video rather than a computer-generated animation. Thus, its interactivity with the user is limited. Since the structure (or connectivity) per reconstructed polygonal mesh is different, simple animation techniques such as warping the mesh to track the user are not straightforward at present. Having separate meshes for each frame also increases the size of the media. Nevertheless, these limitations will be overcome as the technology matures, and mesh operations will be applicable as VV mesh tracking improves.

This project hypothesized that humorous VV AR applications would be appealing and interesting for visitors to the museums and that there is a requirement for further research into the elements that influence the perception of functionality, usability, and user experience in the development of the museological paradigm. What follows below is the documentation of a pilot study (in the Long Room) that was designed to explore the hypotheses outlined in Section 1, measuring the appeal and interest of this pilot AR scene, and eliciting subjective feedback that will inform further research into the area.

## 5 USER STUDY

### 5.1 Methodology

In this study, the Library of Trinity College Dublin's email lists were used to make a public call for participation. Respondents were then invited to attend the Old Library. Upon their visit, the participants were presented with a 3D VV representation of Dean Jonathan Swift. The platforms chosen for delivery were a tablet device (Apple iPad version 6) and an HMD (first-generation Microsoft HoloLens). The platform conditions were randomized so there was no potential for a systematic difference between these conditions to appear. Immediately after each condition, participant responses were collected via a pen and paper questionnaire that included five-point Likert scales and open-ended questions. A high-level questionnaire was developed to assess the successes and failures of the application. The main area of address was the quality of the users' experience, from a technology-in-use point of view, in which the content was also considered.

The focus of the experiment was to determine the appeal of a pilot VV AR app for CH, whether the humorous presentation mode was plausible for museum visitors, and whether one of the AR display devices was perceived

[1]Jonathan Swift in VR/AR- Long Room Project – https://v-sense.scss.tcd.ie/creative-experiments/jonathan-swift-in-vr-ar-long-room-project/

(a) Participant using HMD (Swift model added for visualization).

(b) Participant using tablet.

Fig. 2. Equipments used for the user study.

to be more suitable than the other. The questionnaire also addressed an important dichotomy, raised by Vainstein et al. (2016), that weighs the implications of asking the museum "visitor to hold [a] guide and look at its screen", against donning an HMD, which frees the hands and permits the user to look at the real objects. At this time, quality of experience data was also collected, to be reported upon in a separate paper (Zerman et al. 2020). Ultimately, the goal of the current manuscript was to ascertain if the concept was suitable to expand into a larger museum-wide application. As this paper aims to explore and identify specific aspects of the overall user experience, such as the appeal, the format of the information disclosure, the users' level of interest, and their level of comfort, a bespoke line of questioning was created. Moreover, this broadly facilitated in assessing the various research tools available and informing what areas need further deeper investigation, therefore, both quantitative and qualitative questions were included.

### 5.2 Participants

A total of 17 participants were recruited for the study; between the ages of 25 and 65. The participants' occupations included librarians, administrators, researchers, and staff in the humanities, and graduate students of arts-related subjects. The Long Room of the Old Library is normally open to tourists during business hours seven days a week and has a very large throughput of visitors. By conducting the user tests outside opening hours, participants could interact with the technologies and move around uninterrupted. This allowed participants to concentrate on the story (in terms of the subjective appeal/quality questions) and to compare both platforms, thereby facilitating accurate and quality feedback.

### 5.3 Apparatus

The AR application presented a 3D VV representation of Dean Jonathan Swift as he regales the viewer with an anecdote. A tablet and an HMD were chosen to compare different display modalities, for this purpose, the Microsoft Hololens and Apple iPad were chosen. As the application was designed for individual users, headphones were used for the audio output on the iPad, and for the HoloLens, the built-in speakers were used.

### 5.4 Setup & procedure

The participants were welcomed at the entrance of the Library of Trinity College Dublin, briefed on the experimental procedures, given the opportunity to ask questions, and were then shown to the Long Room. The technology was explained and demonstrated, then the participants were encouraged to find Swift's bust, and view the VV from various viewpoints, which they all did. Specifically, the participants viewed the VV directly facing Swift, moving slowly around the VV in an arc of approximately 120 degrees, gathering a sense of 3D depth;

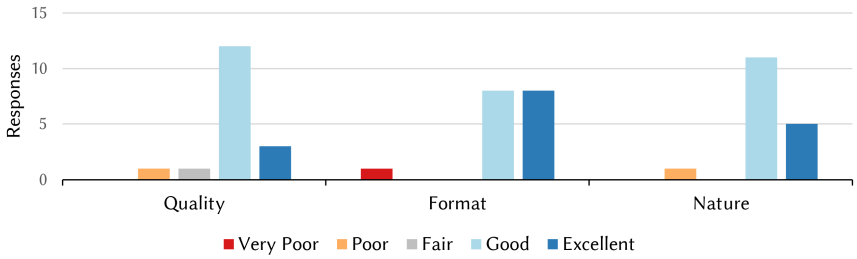



Fig. 3. Participant responses to the appeal of the application measured across 5-point Likert scales

however, some users were also timid in their movements around the space, with few participants moving around the 3D character to see Swift from a profile point-of-view. During this time, participants were holding the tablet or wearing the HMD (each participant used both devices in a randomized order) see Figure 2. After the presentation, the participants were asked to fill in the questionnaire. Each session of the study lasted approximately 20 minutes, comprising of 5 minutes for introductions, 5 minutes time-on-task, and 10 minutes post-task, filling out the questionnaire.

## 6 RESULTS

The data collected from the questionnaire were collated and analyzed in SPSS (a software package used for statistical analysis) and MaxQDA (a software program designed for computer-assisted qualitative and mixed methods data and text analysis), identifying relationships between both quantitative and qualitative feedback. The readers should note that statistical analysis was only performed to find possible indications of significance, therefore, non-parametric tests (e.g., Friedman Test or Wilcoxon Signed Rank Test) were used since the number of participants was limited. Qualitative feedback was coded with a bottom-up approach, generating coded materials from the collected materials directly.

### 6.1 Appeal of application

Regarding the deployment of VV techniques in combination with AR technology for delivering the Jonathan Swift experience, the participants rated the appeal of the application over three relative scales, see Figure 3:

(1) The quality of the application: vis-à-vis an actor playing the part of a character who discloses historical information.
(2) The format of information disclosure: the type of technology used and how it compares to existing museum technologies like audio guides.
(3) The nature of the disclosure: the whimsical, humorous, and peripheral nature of the story, and its playful mode of delivery, versus formal, pertinent information that is expected in traditional museum settings.

When asked to rate the quality of the application, a rating of "Good" was concluded by all participants (n = 17; M = 4.03; SD = 0.67; CI = 0.69). Furthermore, participants also rated the format of information disclosure as also being "Good" (n = 17; M = 4.29; SD = 0.99; CI = 1.01), see Figure 3. Finally, when rating nature of disclosure in story delivery, the participants rated the appeal of the story delivery as "Good" (n = 17; M = 4.18; SD = 0.73; CI = 0.75). The results of a Friedman Test indicated that there was no statistically significant difference between participant ratings of application appeal across the three scales (Quality, Format, and Nature); $x2$ (2, n = 17) = 2.88, $p > 0.05$. Therefore, inspections of the median values for all categories (Md = 4) indicated an overall rating of "Good" for user evaluations of application appeal.

*6.1.1 Qualitative analysis of the appeal of AR application.* Participants were asked to appraise and offer feedback on the quality of the application, the format of information disclosure, and the nature of the disclosure. These questions elicited feedback relating to the VV telling a historical anecdote in a whimsical, blasé manner, versus the familiar museological format of only disclosing formal, pertinent information. By expanding upon their answers, participants justified their scoring of the appeal of the application; a content analysis of these results revealed four main areas of concern: education, fidelity, entertainment, and the general concept.

*6.1.2 Education.* When regarding the educational merits of the experience, the cohort's responses primarily focused on the learning process and the accessibility of the content, for example, "I learned something" and "[It] was easy to follow". In particular, the dialogue and information it contained were labeled as "good and comprehensible". The educational and novel qualities of the VV, delivered conversationally, were described as intriguing and participants stated that they provided insight into how the personality experienced life in bygone times. Negative feedback related to lack of historical specificity; for example, "[It] was lacking in detail a bit on [sic] historical info". Furthermore, the participants identified that if the situational delivery was to be within the library, the appeal of the application could potentially also be achieved by presenting more factual, historical information relevant to Trinity College, Dublin city, and 18th-century culture. Participants mentioned that they liked the details about the Dean punishing him for leaving campus but they would have liked to learn more about his campus works. Furthermore, the participants also expressed an awareness of the potential of AR technology for learning and knowledge building, and how this technology lends itself to the whimsical nature of the story vis-à-vis the context of delivery, within the Long Room. Considering these comments, the reader should also note that the educational experience is multifactorial and the current controlled conditions for this experiment remove some of the elements of a regular museum visit. To get a better understanding, a more focused field study with regular museum visiting conditions must be conducted.

*6.1.3 Fidelity.* Feedback relating to questions on the quality of the application and the nature of the disclosure, focused on the fidelity of the representation, e.g. "Walking around him, I was more aware of flaws, like the nose", and "I wanted the character to be a bit taller". Furthermore, in terms of the staging, or mise-en-scène, of the character, participants offered comments like, "He [Swift] is looking at one point in space. That is distracting, makes him less present". When appraising the appeal of this technology, participants felt that the technology was futuristic and novel. Criticisms identified technical fidelity issues with synchronization, image quality, and other such technical glitches. These comments were concerned with the quality of the reconstruction (e.g. of the nose) or inaccurate tracking of the users' movements, which is characteristic of the current generation of VV technology. The participant comments show how important visual engagement is to them, and some features (e.g. modifying Swift's posture) might be included as and when VV technology allows.

*6.1.4 Entertainment.* The value of the application, as a platform for delivering an entertaining performance, received mixed responses. Overall, these appraisals considered the "engaging" nature of the application, the length of the presentation, and the "relaxed and conversational manner" of the actor's delivery. It was generally agreed that by delivering whimsical historical trivia, the application humanized Swift's story, making it potentially "more accessible" to some users. To support this, participants stated: "I liked the presentation being less formal. I prefer audio-visuals to reading a lot of info", and "The information was interesting and relevant to understand the personality of Swift". However, the cohort also offered critical appraisals of the application, some describing the application as a "poor rendition, content not engaging".

*6.1.5 General concept.* Conceptually, the appeal of the application was generally well-received. Positive comments affirmed that the content had made a lasting impression and intrigued participants to want to know more, within the context of the application delivery space. The potential to further spatialize the experience was suggested; although the application "Felt like it fit[ted] in well", the character could have interacted with the library space

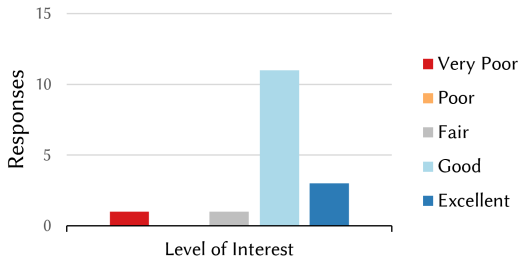



Fig. 4. Participant responses to the level of interest, or usefulness, of the story measured across a 5-point Likert scale

further, by having "him play to a crowded library [addressing] the people all around him wandering around [sic]". Regarding a broader spatialized experience, one outlying participant commented on how the involvement of Swift was distracting from the overall architectural beauty of the Long Room experience, describing the AR intervention as lacking association with space, and, more generally, these devices are "too narrow in focus and aspatial".

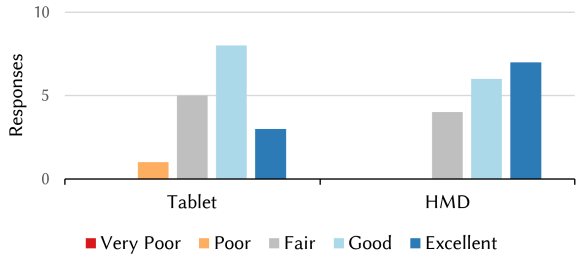
## 6.2 Level of interest

The participants' interest in the application content was measured concerning how they appraised the "usefulness", of the story, in terms of their overall visitor experience of the Long Room. In this context, the application was rated as "Good" (n = 16; M = 3.94; SD = 0.93; CI = 0.99), see Figure 4.

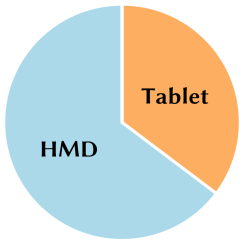
*6.2.1 Qualitative analysis of the level of interest or usefulness of the story.* When asked to explicate their rating, the content analysis revealed two main areas of concern relating to the participants' level of interest: education and entertainment.

*6.2.2 Education.* From an educational perspective, the participants acknowledged the "anecdotal" quality of the AR experience: "It would have been good to have an anecdote tie in with the library space or its bust". This was not interpreted as a negative characteristic; instead, it was identified as a narrative quality that could have benefited from more a detailed description regarding the library as a whole. The participants, if they were not already aware, learned that Swift was a student at Trinity College Dublin; however, some cohorts wanted to know more about what books he published, and the location and his most famous works. One comment referred to the lack of relation between the architectural space and the story. While thought-provoking and edifying for some, the educational elements of the story could have been improved with more contextualized data. Several participants identified that they were actively interested in Swift and his work and delighted in the narrative, but remarked that "[if] one is not already interested in the character, it may be less interesting". Some participants also mentioned that the script caused some confusion, as they did not initially understand the story and had to wait for it to repeat. This feedback was useful to consider when preparing AR stories going forward.

*6.2.3 Entertainment.* The story conveys information about the college dean punishing Swift for an indiscretion and reveals that he was a bad student. When considering the entertainment value of the experience, given the nature of the disclosure, the AR content was generally judged as being "very simple to understand and funny". One participant exclaimed, "This is what visitors would thrill to see". Although "it didn't feel kitschy" to one participant, others expressed that it was "good but needs to improve", or there's "always room for improvement". Participants were generally entertained, enjoyed the humorous nature, and thought the overall Long Room experience was




(a) Participant responses for comfort measured across 5-point Likert scales.




(b) Participant perferences.

Fig. 5. Participant responses to the ease of use.

more interesting and informative because of it. The participants enjoyed the monologue's anecdotal, non-pertinent information because it inferred Swift's human side, a factor often neglected for memorialized historical figures.

In summary, the manifestation of Swift in the Long Room positively enhanced the level of interest the participants experienced in the Library of Trinity College Dublin. The visual presentation animated the museum experience by presenting the participants with a novel representation and story, indicating the potential of expanding this type of CH experience. However, some participants noted that the story lacked contextualization in the immediate architectural space and, if one was not already invested in the character, the experience may have been of lesser interest. Furthermore, novelty effects might also have been influential as our participants used new technology in a quiet space without being museum fatigued. Therefore, participants may have reported increased levels of interest. The novelty effect is further discussed in Section 7.

## 6.3 Ease of use: HMD vs tablet

To compare each device's ease of use, participants were asked to rate their ease in using the tablet and HMD devices. Overall, participants similarly rated the HMD (M = 4.18; SD = 0.81; CI = 0.83) and the tablet (M = 3.76; SD = 0.83; CI = 0.85), see Figure 5.(a). A Wilcoxon Signed Rank Test revealed that there was no statistically significant difference in the rating of comfort, $z = -1.51$, $p > 0.05$, with a medium effect size ($r = 0.37$). The median score of comfort for each device was, therefore, considered as "Good" for both devices.

*6.3.1 Qualitative analysis of ease of use.* To better understand the differences between the two platforms, after using both devices, the participants were asked to describe their experiences for each device and retrospectively compare. The cohort was to consider their personal preferences towards the potential of each device for use in a CH context and specify which device they would prefer to see deployed in museological applications, see Figure 5.(b). Overall, the content analysis revealed that the participants expressed a preference for the HMD due to immersion and realism (65%). This presents interesting data on the experiences of the users, both quantitatively (in the previous sections) and qualitatively (discussed in more detail below). The content analysis revealed three main areas: visual quality, limitations of the technology, and immersion and realism.

## 6.4 Visual Quality, Limitations of Technology, and Immersion

In a concurrent quality of experience study conducted in the Long Room of the Old Library using the same VV stimuli (Zerman et al. 2020), we identified three main aspects concerning the overall user experience for museum-goers when using the different platforms: visual quality, limitations of the technology, and immersion. Therefore, we believe that these findings are relevant for discussion in this manuscript and are reported here.

*6.4.1 Visual Quality.* Responses towards the visual quality of the character were mostly positive; however, there were also some aspects that the users indicated that they would like to see improved. Overall, the tablet was found to have a better and higher fidelity representation compared to the HMD. This is partly due to the infancy of the HMD display technologies and is bound to improve with time. Although the participants enjoyed the application (possibly due to novelty effects, see Section 7), they were also critical of the artifacts caused due to reconstruction and tracking errors. These comments point out a possible venue for improvement.

*6.4.2 Limitations of Technology.* Participants were critical of the current state-of-the-art AR display and VV technology, particularly when commenting on pixelization, synchronization of playback, and real-world scene tracking; with particular focus on Swift's face. Concerning the hardware, they were critical of the narrow field of vision and a distracting image-flicker. Directly comparing the two technologies, participants noted that the imperfections – like loss of scene tracking, loss of audiovisual synchronization, and shaky/flickering visuals – were more obvious on the tablet, but that they detracted minimally from the experience. Conclusions arising from this data indicated that "the tablet's higher resolution and image fidelity made the technical imperfections more noticeable" (Zerman et al. 2020).

*6.4.3 Immersion.* Overall, the application was successfully delivered on both devices, in terms of the global measure of the quality of experience. Participants commended the application for its immersion, stating that the representation of Swift was very lifelike and that they had the sensation of conversing with a real person. As one user stated: "[Swift] was given a very 'characteristic' tone, that is, one feels they're in front of a person from the past" (Zerman et al. 2020). When comparing the two devices, the participants also commented that the HMD was more immersive compared to the tablet, even though the tablet had better visual quality, as mentioned above. As reported by Zerman et al. (2020), participants stated that "even though the quality of representation on HoloLens was not as good as iPad, the HoloLens was still a more immersive compelling experience". Regarding the clarity of the audio, the tablet (with headphones) was found to be superior but this was also criticized for blocking the ambient sounds of the library, isolating the participant from the general CH environment. Participants commented upon and criticized the non-procedural, non-interactive nature of the pre-recorded VV video, for example, the head and body orientation of the VV figure did not reconfigure with the user's position, and that Swift's gaze did not track with their movements either. Participants would, therefore, have preferred if the model had tracked their movement and responded to their ego-centric actions. Similarly, participants also noticed that the sound was not coming from the direction of Swift, and they mentioned that using spatial sound would have increased the immersion factor of the application.

## 6.5 Potential for use in other CH applications and further development

When asked if the participants would like to see this type of application rolled out in other CH settings, the content analysis of results revealed that 94% of respondents indicated that they would. Furthermore, 71% of the participants said that they would be inclined to purchase an application for their mobile phone for the enhancement of museum experiences.

Participants were asked to comment on what other Long Room artifacts they would like to see augmented using mixed reality technology. High-level suggestions covered a "Welcome to the long room" mobile application, a fully guided tour experience, and other novel ideas for thematic links to the Library of Trinity College Dublin exhibits, like "a monk that speaks about the book of Kells". Others suggested that additional busts could be included in the experience, together with other interesting Dublin characters, such as Claude Gilbert, Thomas Lefroy, Shakespeare, Wolfe Tone, and Bram Stoker. The user cohort further identified several other artifacts within the library that could be used to enhance the AR experience, including the Old Library books, Brian Boru's Harp, the 1916 Proclamation of the Irish Republic, and other tangible exhibition items. Further ideas

suggested using AR for the creation of a more complete historic scene adjacent to Swift by animating characters in 18th-century garb, juxtaposing the contemporary audience with historic characters within the Long Room. One participant suggested interactive character actors "to be able to view a few 'choice' books from the shelves. Maybe a character could climb one of the ladders to show the library as it was functioning". The library building itself was included in some responses, suggesting that the ladders, the large wooden spiral staircase, and carpets could all be incorporated into a building-specific story that conveyed the responsibilities of the library, explaining preservation protocols, and portraying people who take care of the space. The history of the building, including the structure and significant events that had occurred there over time, was also proposed as a point of interest.

## 7 DISCUSSION

### 7.1 Appeal

From the results of our pilot study, we can summarize our participants' receptiveness to the use of humorous VV content delivered via AR technology in a CH context. The high-level feedback we received in this formative study relays our participants' attitudes towards the appeal of playful, humorous content, their level of interest in it, the ease of use of AR technology, and how it affects their experiences and their thoughts about other potential uses of AR in the Long Room context. The vision for the expanded project concerns scaling up the concept to include multiple exhibits and encouraging visitors to discover humorous, but informative, VV anecdotes relating to the exhibits, thereby constructing a personalized meta-narrative that reflects their trajectory through the museum. This will be inferred from the singular experience on which the results of this pilot study are based. The appeal of the AR content was, overall, rated as being "Good", suggesting that the VV content provided enjoyment, amusement, and a positive emotional environment. There is an established academic tradition advocating the benefits of communicating scholarly content in humorous or playful ways. Creating a humorous, ludic learning environment, compels the listener's mind to a state of reduced anxiety and increased self-motivation (Berk 1996). Physiologically speaking, laughter and humor exercise the chest muscles and oxygenate the blood, thereby improving circulation and respiration, ultimately, facilitating the release of endorphins into the bloodstream and reducing anxiety (ibid). Humor can assist listener engagement by adding variety to dialogue, providing enjoyment and laughter, and creating a positive emotional and social environment, thereby lowering individual, or group, defenses, and enhancing social bonding and openness (Bryant et al. 1980; Glenn 2002; Gorham and Christophel 1990; Kaplan and Pascoe 1977; Neumann et al. 2009). This is pertinent to museums where people are corralled into groups (comprised of unfamiliar others) and ushered through heavily regulated (and sometimes constricted) spaces, which can raise anxiety levels. Our participants considered the criteria of education, image fidelity, entertainment, and the overall concept, as the barometers of this judgment. This feedback suggests that most participants enjoyed learning information peripherally, and yet, were also able to relate it to the focus of the exhibition (architecture & early Christian manuscript illumination). However, they also wanted to hear more pertinent information, further balancing anecdotal with historical information. We also found that the users could not separate the visual fidelity of the representation when judging the overall appeal; questions focused on the playful delivery of the story and not the image quality, yet participants nevertheless attributed the lack of visual acuity as being deleterious to the appeal of the experience. Many users appreciated the entertaining nature of the content, as delivered by a professional actor, with many of them declaring their preference for engaging with exhibitions via mediated guidance systems. Others commented that the engaging nature of the character conduced a relaxing atmosphere and facilitated some insight into Swift's personality. These observations were important indicators of the success of the ambiance that we strove to achieve, and support the scholarly discourse advocating that humor can compel participants' into a state of reduced anxiety and increased self-motivation. Finally, our participants expressed their satisfaction with the overall concept and wished to see more of these types

of applications, but with more direct engagement within the spatial context. This assessment also corroborated many of the criticisms surrounding the participants' level of interest.

### 7.2 Interest

The participants rated their level of interest in the application content as "Good", which supports the use of humorous, anecdotal VV apps in museological contexts. Their predominant criteria of judgment included education and entertainment. Most users enjoyed the anecdotal nature of the disclosure and felt that it was thought-provoking and interesting, with many participants expressing satisfaction at learning something new. Interest-related comments that focused on the criterion of entertainment tended to use enthusiastic language about the application, but this could also have been related to the novelty-factor of the HMD. However, concerning both criteria, many of our participants would have liked to further engage with more pertinent, context-related information about the Long Room and its historical contents. This was a salient criticism, that was also articulated in feedback in the appeal section. As well as the social benefits of humor in learning environments, many studies also maintain that humor can improve levels of focus and attention, enhance critical thinking, stimulate a desire to learn more, and heighten the recall of lesson details (Bell 2009; Garner 2006; Hill 1988; Kaplan and Pascoe 1977; Ziv 1988). However, Banas et al. (2011) advises that, although humor is an effective means of gaining attention when it comes to interrogating the positive effects of humor on information retention, empirical evidence is far less unequivocal. They take a position that concurs with Kaplan and Pascoe (1977), holding that humor should be relevant to the instructional material to positively affect learning. Based on the effectiveness of humor for garnering attention and stimulating interest, the enthusiasm and motivation of participants to hear more formal CH information about the Long Room is in agreeance with the current scholarly discourse on humor in education. However, more research is needed to ascertain the positive cognitive effects of the communication paradigm on a complete museum visit, which can only be carried out when the application is further expanded. A long-term goal of this CH research is to develop innovative apps that afford visitors a more enjoyable, memorable, and informal learning experience in CH.

### 7.3 Augmented reality technologies as learning tools

Numerous empirical studies have examined the potential of AR for learning, across a variety of subject areas and age demographics (Chang et al. 2014; Dunleavy and Dede 2014; Ibáñez et al. 2014; Martín-Gutiérrez et al. 2010; Wu et al. 2013). The majority of studies agree that students gain more knowledge and perceive higher levels of "flow experience" (deeper attention, and more enjoyment, reward, and personal fulfillment) in digitally assisted learning situations. Sommerauer and Müller (2014) conducted a quantitative field experiment that measured the effects of teaching mathematics via AR technologies in an informal learning environment. Their field experiment produced strong empirical evidence to support their hypothesis "that museum visitors learn better from augmented exhibits than from nonaugmented exhibits" (Sommerauer and Müller 2014, p. 62). Therefore, contributing strong evidence to the overall argument that AR technologies have a positive effect on learning. Moreover, Sommerauer and Müller provide a useful explanation as to *why* AR can improve learning, by drawing on the cognitive theory of multimedia learning (CTML). This psychological theory argues that learning through words and pictures is better than learning purely through words (Mayer 1997, 2005). Mayer posits design principles for a multimedia-enhanced learning paradigm that is based on the three scholarly assumptions of Paivio (1990), Sweller (2011), and Wittrock (1992).

Sommeraur and Müller also argue that, when implemented properly, many of these principles are immanent to AR learning applications, for example: learning from words and pictures, relating non-contiguous but related information within a singular (exhibition) space, communicating extraneous textual information that is related

to visual content in an aural format and organizing information by highlighting relationships and directing attention within an overall body of knowledge that is too big to ingest in its entirety.

### 7.4 Comparison between HMD and tablet

When participants were asked to comparatively assess their experiences of engaging the same content using a tablet and an HMD, there was found to be no significant differences in user preferences, echoing the findings of Greenfeld et al. (2018); however, in the analysis of the qualitative data, most users expressed a preference for the HMD, reaffirming the findings of Riedlinger et al. (2019). Their preference was based on the HMD's affordance of immersion and interlocutory realism; despite the higher resolution and image fidelity delivered by the tablet, participants were willing to endure a trade-off of these qualities for a greater perception of immersion and conversational presence. The participants also noticed "artifacts" (a term describing holes in the VV or incomplete texturing), which they perceived as "pixilation" or "glitches", disturbing deformations, and lip-sync and scene-tracking errors. The first two errors were caused by inaccuracies in the VV capture, something that is improved with every iteration of the technology. The second error group can be attributed to our playback technologies. As noted in the "Appeal" section, these shortcomings are something that notably irked some users, and caused them to downgrade their rating of the application's appeal. Henceforth, an area for further research is to ascertain the optimal balance between these two desirable but incompatible features: image fidelity and the sense of immersion (which affords interlocutory realism). Users also rated and critiqued the level of immersion concerning the sensation of being directly addressed by Swift, noting that neither the character nor his eyes follow you as you move around. This is another area ripe for research in terms of technical fidelity and the mise-en-scène of VV characters in AR applications.

### 7.5 Potentials for further studies and limitations

Bailenson (2018) suggests that a field trip is a perfect metaphor for VR learning. During a field trip, the class visits a place of significance to the teachings of the classroom. Being there physically holds some gravity to classroom materials, emphasizing that the field trip augments the classroom experience and does not seek to replace it (Dawkins and Young 2020). Similarly, our study highlighted the importance of visiting a CH site and being present – augmenting the CH site, not replacing it. Furthermore, although developing prior knowledge or intrinsic motivations helped prepare our participants for the experience, our visitors were also receptive to the concept of "time for telling", supporting existing knowledge by being told the significance of the materials they are experiencing through narrative (Schwartz and Bransford 1998). Participants expressed the desire to see more of this type of storytelling application in CH contexts, offering some interest in purchasing such an application. However, prevailing criticisms were clear: there needs to be more connected with the locations of various exhibits in the Library of Trinity College Dublin. Although, many participants were excited by its potential and were forthcoming with creative suggestions, fulfilling a more comprehensive, location-specific AR application entails building a logistically much more complicated project.

Our first two hypotheses query the appropriateness of humorous VV content for curatorial information disclosure. Based on the results of our survey it is proposed that these hypotheses are validated; that is, the delivery of humorous, site-relevant, context-aware information, produced using cutting-edge VV techniques and mediated via a humorous AR application, is both appealing and appropriate for analysis in contemporary CH institutes. Furthermore, the discussed scholarly discourses showing the effectiveness of humor and AR technology for teaching and learning in formal/informal learning environments (F/ILEs), bolster the justification for contributing to these scholarly discourses with an innovative AR app for educating in CH contexts. The surrounding literature indicates that each of these strategies, taken individually, can ameliorate, enrich, and brighten ILEs. Therefore, it can be asserted that an AR application combining both of these pedagogical methodologies would be a powerful

storytelling device for any CH experience and that further research, development, and investment in this research area are both needed and justified.

The limitations of using VV in a CH application were also noted. These challenges are related to the technical limitations of the platform, single-user vs multi-user experiences, and the static nature of the volumetric character. For technological advancement, the FOV and the availability/familiarity of the platform will need to be improved upon, which will take time. Currently, our user experiences reported heavily on the novelty of the applications from a novice's perspective and this factor can compound certain measures of newness and unfamiliarity in the application platform. Furthermore, the use of an HMD was a very solitary experience when viewing VV content, that is, it was no longer a shared, communal experience. Finally, VV is captured in a way that does not afford any interactivity. The motion of the character was fixed, such as traditional video, whereas 3D CGI can be programmed to react to visitor interactions, much like is seen in video games. These limitations will be of particular relevance when exploring future human-computer interaction studies of this nature.

## 8 CONCLUSION

The conceptual basis of the presented research concerned building and testing a pilot scene for an AR application that would give a personal, human dimension to inanimate objects of interest within an existing CH site. Unlike much of the existing literature that formulates the basis of our conceptualization, our case-study did not attempt to quantifiably prove or to contribute empirical data to technology in use or museological fields individually. On the contrary, our prototype field-test was applied as a proof of concept, the goal of which was to assess the appeal and appetite for this kind of storytelling strategy in a CH situation, as well as assessing the experimental tools and raising questions for future scientific studies. To do so, we gathered both quantitative and qualitative data, with a focus on garnering end-user feedback on a field dominated by subjectivity: storytelling.

Many participants found the VV appealing and interesting, a result that aligns with our first hypothesis. Although most participants found the representation appealing, some of the participants also noted the limitations of VV technology. Thus, to determine the plausibility of using VV, we can ask the following question: "*Is VV the best representation technique for CH oriented AR applications?*". To answer this, a user study with a more diverse range of content and platforms should be conducted to analyze the use of VV in CH oriented AR applications, including also a comparison of VV with different 3D graphics techniques such as computer-generated imagery. This future research direction should also include various devices and modalities such as audio or visual guides.

The overarching participant views maintain that humorous, playful storytelling is both appropriate and effective in this context, because it enriched the visitors' experiences, and more of this type of work was encouraged. This is in line with the second hypothesis. However, this finding needs to be further tested for its effectiveness in teaching in informal learning environments. This can be formalized in another research question: "*Are playful anecdotes and humorous deliveries better for museum visitors' information retention than more serious, formal deliveries?*". For this purpose, this study should be redone with different types of VVs, comparing the more serious, informative delivery to another with a more whimsical, funny one.

The results of both quantitative and qualitative analyses also align with the last hypothesis. This means that the effects of VV and humorous, playful anecdotes in CH oriented applications should be studied together to measure the unique experiences that each one presents. For this, the research questions mentioned above need to be taken into consideration at the same time. Furthermore, we found that only quantitative analysis might not be enough to understand the differences and additional qualitative analysis tools might be necessary. Also, new approaches might be needed to measure usability for these CH oriented AR applications.

The overall validity of the results of this study are contingent on scaling up the project to include multiple, context-aware narratives, different visual representations (e.g., VV and computer-generated imagery), different styles of information delivery (e.g., serious versus whimsical), and different devices (e.g., audio guides, visual

aids, etc.), either in this museum or another, as well as an experiment design that targets specific elements of CH technology interventions and larger, more diverse, participant engagements. Therefore, based upon the feedback garnered from the presented study, the ambition for further research is to expand the storytelling strategy to include multiple digital/virtual storytellers, corresponding to various major exhibits in a CH context.

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## REFERENCES

Gabriella Arcese, Laura Di Pietro, and Roberta Guglielmetti. 2011. The augmented reality in the cultural heritage sector. In *Proceedings of the QMOD Conference on Quality and Service Sciences 2011*. Servicios de Publicaciones Universidad de Navarra Carretera del Sadar, San Sebastian, 158–170.

Ronald Azuma. 2016. Location-Based Mixed and Augmented Reality Storytelling. In *Fundamentals of Wearable Computers and Augmented Reality* (2nd ed.), Woodrow Barfield (Ed.). CRC Press, Boca Raton, FL, USA, Chapter 11, 259–276. https://doi.org/10.1201/b18703-15

Ronald T. Azuma. 1997. A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments* 6, 4 (1997), 355–385. https://doi.org/10.1162/pres.1997.6.4.355

Chris Baber, Huw William Bristow, Sean-Lee Cheng, Anna Hedley, Yuri Kuriyama, Marc Lien, James Pollard, and Phil Sorrell. 2001. Augmenting Museums and Art Galleries. In *Interact*, Michitaka Hirose (Ed.). IOS Press, Amsterdam, 439–446.

Jeremy Bailenson. 2018. *Experience on demand: What virtual reality is, how it works, and what it can do.* WW Norton & Company, New York.

John A. Banas, Norah Dunbar, Dariela Rodriguez, and Shr-Jie Liu. 2011. A Review of Humor in Educational Settings: Four Decades of Research. *Communication Education* 60, 1 (2011), 115–144. https://doi.org/10.1080/03634523.2010.496867

Mafkereseb Kassahun Bekele, Roberto Pierdicca, Emanuele Frontoni, Eva Savina Malinverni, and James Gain. 2018. A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. *ACM J. Comput. Cult. Herit.* 11, 2 (Mar 2018), 7:1–7:36. https://doi.org/10.1145/3145534

Nancy D. Bell. 2009. Learning about and through humor in the second language classroom. *Language Teaching Research* 13, 3 (2009), 241–258. https://doi.org/10.1177/1362168809104697

Hrvoje Benko, Edward W. Ishak, and Steven Feiner. 2004. Collaborative mixed reality visualization of an archaeological excavation. In *Third IEEE and ACM International Symposium on Mixed and Augmented Reality*. IEEE, Washington, 132–140. https://doi.org/10.1109/ISMAR.2004.23

Ronald A. Berk. 1996. Student ratings of 10 strategies for using humor in college teaching. *Journal on Excellence in College Teaching* 7, 3 (1996), 71–92.

Andrea Brogni, Carlo Avizzano, Chiara Evangelista, and Massimo Bergamasco. 1999. Technological approach for cultural heritage: Augmented reality. In *8th IEEE International Workshop on Robot and Human Interaction. RO-MAN '99 (Cat. No.99TH8483)*. IEEE, Pisa, 206–212. https://doi.org/10.1109/ROMAN.1999.900341

Jennings Bryant, Paul W. Comisky, and Dolf Crane, Jon S. andZillmann. 1980. Relationship between college teachers' use of humor in the classroom and students' evaluations of their teachers. *Journal of Educational Psychology* 72, 4 (1980), 511–519. https://doi.org/10.1037/0022-0663.72.4.511

Kuo-En Chang, Chia-Tzu Chang, Huei-Tse Hou, Yao-Ting Sung, Huei-Lin Chao, and Cheng-Ming Lee. 2014. Development and behavioral pattern analysis of a mobile guide system with augmented reality for painting appreciation instruction in an art museum. *Computers & Education* 71 (Feb 2014), 185–197. https://doi.org/10.1016/j.compedu.2013.09.022

Angeliki Chrysanthi, Constantinos Papadopoulos, Tom Frankland, and Graeme Earl. 2013. 'Tangible Pasts': User-Centred Design of a Mixed Reality Application for Cultural Heritage. In *Archaeology in the Digital Era: Papers from the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton, 26-29 March 2012*, Graeme Earl, Tim Sly, Angeliki Chrysanthi, Patricia Murrieta-Flores, Constantinos Papadopoulos, Iza Romanowska, and David Wheatley (Eds.). Amsterdam University Press, Amsterdam, 31–39. https://doi.org/10.2307/j.ctt6wp7kg.6

Areti Damala, Eva Hornecker, Merel van der Vaart, Dick van Dijk, and Ian Ruthven. 2016. The Loupe: Tangible Augmented Reality For Learning To Look At Ancient Greek Art. *Mediterranean Archaeology and Archaeometry* 16, 5 (2016), 73–85. https://doi.org/10.5281/ZENODO.204970

Oliver Dawkins and Gareth W. Young. 2020. Engaging Place with Mixed Realities: Sharing multisensory experiences of place through community-generated digital content and multimodal interaction. In *Proceedings of the International Conference on Human-Computer Interaction*. Springer, Copenhagen, 1–658.

Steven Dow, Jaemin Lee, Christopher Oezbek, Blair MacIntyre, Jay David Bolter, and Maribeth Gandy. 2005. Exploring Spatial Narratives and Mixed Reality Experiences in Oakland Cemetery. In *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology*. ACM, Valencia, 51–60. https://doi.org/10.1145/1178477.1178484

Matt Dunleavy and Chris Dede. 2014. Augmented Reality Teaching and Learning. In *Handbook of Research on Educational Communications and Technology*, J. Michael Spector, M. David Merrill, Jan Elen, and M. J. Bishop (Eds.). Springer New York, New York, NY, 735–745. https://doi.org/10.1007/978-1-4614-3185-5_59

John H. Falk. 1999. Museums as Institutions for Personal Learning. *Daedalus* 128, 3 (1999), 259–275. http://www.jstor.org/stable/20027574

John H. Falk and Lynn D. Dierking (Eds.). 1995. *Public institutions for personal learning: Establishing a research agenda.* American Association of Museums, Washington.

Randall L. Garner. 2006. Humor in Pedagogy: How Ha-Ha can Lead to Aha! *College Teaching* 54, 1 (2006), 177–180. https://doi.org/10.3200/CTCH.54.1.177-180

Robert Glenn. 2002. Brain Research: Practical Applications for the Classroom. *Teaching for Excellence* 21, 6 (2002), 1–2.

Joan Gorham and Diane M. Christophel. 1990. The relationship of teachers' use of humor in the classroom to immediacy and student learning. *Communication Education* 39, 1 (1990), 46–62. https://doi.org/10.1080/03634529009378786

Adam Greenfeld, Artur Lugmayr, and Wesley Lamont. 2018. Comparative Reality: Measuring User Experience and Emotion in Immersive Virtual Environments. In *IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*. IEEE, Taichung, 204–209. https://doi.org/10.1109/AIVR.2018.00048

Tony Hall, Luigina Ciolfi, Liam Bannon, Mike Fraser, Steve Benford, John Bowers, Chris Greenhalgh, Sten-Olof Hellström, Shahram Izadi, Holger Schnädelbach, and Martin Flintham. 2001. The Visitor As Virtual Archaeologist: Explorations in Mixed Reality Technology to Enhance Educational and Social Interaction in the Museum. In *Proceedings of the 2001 Conference on Virtual Reality, Archeology, and Cultural Heritage*. ACM, Glyfada, 91–96. https://doi.org/10.1145/584993.585008

Ping-Hsuan Han, Yang-Sheng Chen, Iou-Shiuan Liu, Yu-Ping Jang, Ling Tsai, Alvin Chang, and Yi-Ping Hung. 2019. A Compelling Virtual Tour of the Dunhuang Cave With an Immersive Head-Mounted Display. *IEEE Computer Graphics and Applications* 40, 1 (2019), 40–55. https://doi.org/10.1109/MCG.2019.2936753

Deborah J. Hill. 1988. *Humor in the classroom: A handbook for teachers (and other entertainers!).* Charles C Thomas Pub Ltd, Springfield, IL, USA.

María Blanca Ibáñez, Ángela Di Serio, Diego Villarán, and Carlos Delgado Kloos. 2014. Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. *Computers & Education* 71 (2014), 1–13. https://doi.org/10.1016/j.compedu.2013.09.004

Robert M. Kaplan and Gregory C. Pascoe. 1977. Humorous Lectures and Humorous Examples: Some Effects upon Comprehension and Retention. *Journal of Educational Psychology* 69, 1 (1977), 61–62. https://doi.org/10.1037/0022-0663.69.1.61

Kangsoo Kim, Byung-Kuk Seo, Jae-Hyek Han, and Jong-Il Park. 2009. Augmented Reality Tour System for Immersive Experience of Cultural Heritage. In *Proceedings of the 8th International Conference on Virtual Reality Continuum and Its Applications in Industry*. ACM, Yokohama, 323–324. https://doi.org/10.1145/1670252.1670325

Karol Kwiatek and Martin Woolner. 2009. Embedding interactive storytelling within still and video panoramas for cultural heritage sites. In *International Conference on Virtual Systems and Multimedia*. IEEE, Vienna, 197–202. https://doi.org/10.1109/VSMM.2009.36

Fotis Liarokapis. 2007. An augmented reality interface for visualizing and interacting with virtual content. *Virtual Reality* 11, 1 (2007), 23–43. https://doi.org/10.1007/s10055-006-0055-1

Vincenzo Lombardo and Rossana Damiano. 2012. Storytelling on mobile devices for cultural heritage. *New Review of Hypermedia and Multimedia* 18, 1-2 (2012), 11–35. https://doi.org/10.1080/13614568.2012.617846

Nadia Magnenat-Thalmann and George Papagiannakis. 2005. Virtual worlds and augmented reality in cultural heritage applications. In *Recording, Modeling and Visualization of Cultural Heritage*. CRC Press, Ascona, 1–11.

Jorge Martín-Gutiérrez, José Luís Saorín, Manuel Contero, Mariano Alcañiz, David C. Pérez-López, and Mario Ortega. 2010. Design and validation of an augmented book for spatial abilities development in engineering students. *Computers & Graphics* 34, 1 (2010), 77–91. https://doi.org/10.1016/j.cag.2009.11.003

Richard E. Mayer. 1997. Multimedia learning: Are we asking the right questions? *Educational Psychologist* 32, 1 (1997), 1–19. https://doi.org/10.1207/s15326985ep3201_1

Richard E. Mayer (Ed.). 2005. *The Cambridge Handbook of Multimedia Learning.* Cambridge University Press, Cambridge, UK.

Takeshi Naemura, Yasuaki Kakehi, Tomoko Hashida, Young ah Seong, Daisuke Akatsuka, Takuro Wada, Takashi Nariya, Totaro Nakashima, Ryo Oshima, and Takafumi Kuno. 2010. Mixed Reality Technologies for Museum Experience. In *Proceedings of the 9th ACM SIGGRAPH Conference on Virtual-Reality Continuum and Its Applications in Industry*. ACM, Seoul, 17–20. https://doi.org/10.1145/1900179.1900182

David L. Neumann, Michelle Hood, and Michelle M. Neumann. 2009. Statistics? You Must be Joking: The Application and Evaluation of Humor when Teaching Statistics. *Journal of Statistics Education* 17, 2 (2009), 1–16. https://doi.org/10.1080/10691898.2009.11889525

Néill O'Dwyer, Jan Ondřej, Rafael Pagés, Konstantinos Amplianitis, and Aljoša Smolić. 2018. Jonathan Swift: Augmented Reality Application for Trinity Library's Long Room. In *Interactive Storytelling*, Rebecca Rouse, Hartmut Koenitz, and Mads Haahr (Eds.). Springer International

Publishing, Dublin, 348–351. https://doi.org/10.1007/978-3-030-04028-4_39

Fumio Okura, Masayuki Kanbara, and Naokazu Yokoya. 2015. Mixed-Reality World Exploration Using Image-Based Rendering. *ACM J. Comput. Cult. Herit.* 8, 2 (Mar 2015), 9:1–9:26. https://doi.org/10.1145/2700428

Laura Serra Oliva, Anna Mura, Alberto Betella, Daniel Pacheco, Enrique Martinez, and Paul Verschure. 2015. Recovering the history of Bergen Belsen using an interactive 3D reconstruction in a mixed reality space the role of pre-knowledge on memory recollection. In *Digital Heritage*. Springer International Publishing, Granada, 163–165. https://doi.org/10.1109/DigitalHeritage.2015.7413860

Néill O'Dwyer, Nicholas Johnson, Enda Bates, Rafael Pagés, Jan Ondřej, Konstantinos Amplianitis, David Monaghan, and Aljoša Smolić. 2017. Virtual play in free-viewpoint video: Reinterpreting Samuel Beckett for virtual reality. In *IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct)*. IEEE, Nantes, 262–267.

Rafael Pagés, Konstantinos Amplianitis, David Monaghan, Jan Ondřej, and Aljosa Smolić. 2018. Affordable content creation for free-viewpoint video and VR/AR applications. *Journal of Visual Communication and Image Representation* 53 (2018), 192–201. https://doi.org/10.1016/j.jvcir.2018.03.012

Allan Paivio (Ed.). 1990. *Mental Representations: A Dual Coding Approach*. Oxford University Press, New York, NY, USA.

George Papagiannakis, Sébastien Schertenleib, Brian O'Kennedy, Marlene Arevalo-Poizat, Nadia Magnenat-Thalmann, Andrew Stoddart, and Daniel Thalmann. 2005. Mixing virtual and real scenes in the site of ancient Pompeii. *Computer Animation and Virtual Worlds* 16, 1 (Feb 2005), 11–24. https://doi.org/10.1002/cav.53

Sasithorn Rattanarungrot, Martin White, Zeeshan Patoli, and Tudor Pascu. 2014. The Application of Augmented Reality for Reanimating Cultural Heritage. In *Virtual, Augmented and Mixed Reality. Applications of Virtual and Augmented Reality*, Randall Shumaker and Stephanie Lackey (Eds.). Springer International Publishing, New York, 85–95. https://doi.org/10.1007/978-3-319-07464-1_8

Urs Riedlinger, Leif Oppermann, and Wolfgang Prinz. 2019. Tango vs. HoloLens: A Comparison of Collaborative Indoor AR Visualisations Using Hand-Held and Hands-Free Devices. *Multimodal Technologies Interact.* 3, 2 (2019), 1–15. https://doi.org/10.3390/mti3020023

Daniel L. Schwartz and John D. Bransford. 1998. A time for telling. *Cognition and Instruction* 16, 4 (1998), 475–522.

Chandler G. Screven. 1986. Exhibitions and Information Centers: Some Principles and Approaches. *Curator: The Museum Journal* 29, 2 (1986), 109–137. https://doi.org/10.1111/j.2151-6952.1986.tb01433.x

Peter Sommerauer and Oliver Müller. 2014. Augmented reality in informal learning environments: A field experiment in a mathematics exhibition. *Computers & Education* 79 (Oct 2014), 59–68. https://doi.org/10.1016/j.compedu.2014.07.013

John Sweller. 2011. CHAPTER TWO - Cognitive Load Theory. In *Psychology of Learning and Motivation*, Jose P. Mestre and Brian H. Ross (Eds.). Vol. 55. Academic Press, Cambridge, 37–76. https://doi.org/10.1016/B978-0-12-387691-1.00002-8

Natalia Vainstein, Tsvi Kuflik, and Joel Lanir. 2016. Towards Using Mobile, Head-Worn Displays in Cultural Heritage: User Requirements and a Research Agenda. In *Proceedings of the 21st International Conference on Intelligent User Interfaces*. ACM, Sonoma, 327–331. https://doi.org/10.1145/2856767.2856802

Vassilios Vlahakis, Nikolaos Ioannidis, John Karigiannis, Manolis Tsotros, Michael Gounaris, Didier Stricker, Tim Gleue, Patrick Daehne, and Luís Almeida. 2002. Archeoguide: An augmented reality guide for archaeological sites. *IEEE Computer Graphics and Applications* 22, 5 (Sep 2002), 55–60. https://doi.org/10.1109/MCG.2002.1028726

Merlin C. Wittrock. 1992. Generative Learning Processes of the Brain. *Educational Psychology* 27, 4 (1992), 531–541. https://doi.org/10.1207/s15326985ep2704_8

Hsin-Kai Wu, Silvia Wen-Yu Lee, Hsin-Yi Chang, and Jyh-Chong Liang. 2013. Current status, opportunities and challenges of augmented reality in education. *Computers & Education* 22 (Mar 2013), 41–49. https://doi.org/10.1016/j.compedu.2012.10.024

Emin Zerman, Gareth W. O'Dwyer, Néill amd Young, and Aljosa Smolic. 2020. A Case Study on the Use of Volumetric Video in Augmented Reality for Cultural Heritage. In *Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society (NordiCHI '20)*. ACM, New York, NY, USA. https://doi.org/10.1145/3419249.3420115

Katja Zibrek, Elena Kokkinara, and Rachel Mcdonnell. 2018. The Effect of Realistic Appearance of Virtual Characters in Immersive Environments - Does the Character's Personality Play a Role? *IEEE Transactions on Visualization and Computer Graphics* 24, 4 (Apr 2018), 1681–1690. https://doi.org/10.1109/TVCG.2018.2794638

Avner Ziv. 1988. Teaching and Learning with Humor. *The Journal of Experimental Education* 57, 1 (Mar 1988), 4–15. https://doi.org/10.1080/00220973.1988.10806492

Michael Zoellner, Jens Keil, Timm Drevensek, and Harald Wuest. 2009. Cultural Heritage Layers: Integrating Historic Media in Augmented Reality. In *15th International Conference on Virtual Systems and Multimedia*. IEEE, Vienna, 193–196. https://doi.org/10.1109/VSMM.2009.35