Mixed reality experiences in museums:
Exploring the impact of functional elements of the devices on immersive experiences and post-experience behaviours

Abstract

This paper contributes to the debate on MR technology in the museum setting by investigating how and to what extent functional elements of the MR devices affect experiences and drive post-experience behaviours. It bridges several research gaps in MR investigation, demonstrating unexplored causal relationships between the functionality of MR devices and museum experiences and post-experience behaviours, which have been investigated separately. The research confirms that MR advances empower the museum's mission of heritage valorisation and education, which drive new immersive experiences and behaviours. It introduces insights to overcome technological limitations as a challenge for practitioners as well as a flourishing area of investigation.

Keywords: mixed reality, cultural heritage museum, immersive devices, functional elements, immersive experiences, post-experience behaviours

1. Introduction

Advances in digital technologies are reshaping the human–technology interaction in the physical–virtual continuum and are calling academics, practitioners and policymakers to look beyond today's "tech-clash" and leverage on "provocative thinking, transformative insights, tangible outcomes" (Accenture, 2020). Augmented reality (AR), virtual reality (VR) and mixed reality (MR) represent mainstreams in this transformation involving diverse contexts of application, including tourism, hospitality and cultural heritage (Bae et al., 2020; Buhalis *et al.*, 2019; Guttentag, 2010; Loureiro *et al.*, 2020; Yung and Khoo-Lattimore, 2019). Immersive technologies have been adopted to reduce the negative impacts of tourism by proposing alternative accessible experiences (e.g., museum virtual experiences) and introducing new communication and marketing tools that enhance pre-experience value and create the desire to visit the destination (Loureiro *et al.*, 2019).

MR became a trending topic in the museum and cultural heritage investigation as a smart technological solution that integrates augmented and virtual elements, replicating or transforming reality or past events (Loureiro *et al.*, 2019). Museums and other cultural heritage organisations exploit MR opportunities to reshape physical space and heritage exhibitions (e.g., monuments, archaeological sites, paintings and historical artefacts). They capitalise on new technological multi-sensory environments and the value of digital storytelling (Loureiro *et al.*, 2019), redefining the relationship between visitors and the tangible and intangible cultural heritage (Bekele, 2019; Flavián *et al.*, 2019; Rahaman *et al.*, 2019; Trunfio *et al.*, 2022; Wang and Xia, 2019).

Scholars tend to emphasise the disruptive role of new realities in the museum setting by reframing traditional cultural experiences, such as heritage preservation and promotion, and transforming the cultural site visit into a multi-experiential, sensorial, and emotional experience (Bec *et al.*, 2019; Fenu and Pittarello, 2018; Flavián *et al.*, 2021; Guttentag, 2010; Trunfio *et al.*, 2020, 2022). Immersive realities have been presented as innovative forms of visitors' interaction and participation (e.g., gamification) to enhance the value of the cultural experience and enrich experiential learning with edutainment, creating unusual forms of enjoyment and escape (Bec *et al.*, 2019; Fenu and Pittarello, 2018; Flavián *et al.*, 2021; Guttentag, 2010; Trunfio *et al.*, 2020, 2022).

Although the prevailing literature considers several advantages of MR experiences in the museum, diverse barriers and constraints in technology acceptance, adoption and use are manifested in theoretical and practical-led papers. One seminal paper on immersive reality in museums and art galleries points out the necessity to understand functional requirements from a visitor's point of view, underlining technical and design investigation as the main challenges for scholars (tom Dieck *et al.*, 2016).

Several studies have focused on partial aspects of the ergonomic evaluation of MR devices to identify user requirements to adopt functioning and well-perceived wearable applications (Bach and Scapin, 2004; Bekele et al., 2018; Trunfio *et al.*, 2020). Others offer opportunities to investigate critical aspects of the continuity between the real world and the virtual world (immersion and presence) and evaluate the visitors' roles and behaviours in the cultural experience (Bae et al., 2020; Bekele et al., 2018; Cuni et al., 2015; Lee et al., 2020; Pallud, 2017; Trunfio *et al.*, 2020). Barriers to adoption and user experience have been identified in the immersive technological limitations, cultural content complexity, human factors (Bekele *et al.*, 2018) and the market's stand-alone value (Laurell *et al.*, 2019).

Research studies on immersive technologies vary between those concentrating on the functional aspect of the technological devices − which drive acceptance, adoption and use − and those related to the diverse typologies of technology-driven experiences in the museum and cultural heritage organisations.

Recently, a conceptual model measuring functional elements of MR devices and immersive experiences in the museum has been applied (Trunfio *et al.*, 2020). Despite its proposal of a list of items measuring separately functional aspects of the MR technological devices and immersive experiences, scholars continue to investigate them separately. The influence of MR technological devices on cultural heritage experiences continues to represent a grey area of investigation.

An increasing number of empirical tourism studies have investigated diverse aspects and impacts of immersive technologies as a multifaceted phenomenon. For example, investigating the role of AR in cultural heritage tourism, a study showed how AR satisfaction influences behaviour intention or the desire to visit a heritage site and recommend it to others (Chung et al., 2018).

In addition, there is tourism research with the service management perspective. It investigated how the technology-driven innovation of the museum service model reshapes human-to-technology and technology-to-organisation interactions, impacting overall visitor experience and satisfaction. The empirical analysis considers four main aspects of the museum visit, such as immersive technologies (AR and VR), physical museum elements (e.g., exhibition content), general museum organisation and the role of reception staff (Trunfio *et al.*, 2022).

A number of studies explored the effectiveness of VR technology in promoting post-experience behaviour considering diverse tourism areas of research. Research on theme parks analysed the impact of the VR on visitors' experience and behaviour, evaluating intent to visit and intent to recommend as possible post-experience effects (Wei et al. 2019). Other studies, adopting a perspective of the destination's pre-visit experience, have considered how VR provides an opportunity for tourists to experience a destination in advance and drive a potential tourists' visit intention (Kim et al., 2020; Tussyadiah et al. 2018).

Despite the growing importance of immersive experience research and the number of prior empirical studies investigating the effectiveness of AR and VR in tourism, the post-experience behaviour in the museum under MR conditions remains an undeveloped area of investigation.

A key question challenges the academic investigation: How and to what extent do the MR devices' ergonomic characteristics affect immersive experiences in the museum and drive post-experience behaviours? This investigation appears relevant in providing fresh knowledge to mitigate two research gaps: firstly, the relationship between the functionality of the MR devices and the museum experiences, which has been measured separately; secondly, the post-experience behaviour in the museum under MR conditions, which remains an undeveloped area of investigation.

Shedding light on the role and limitation of the single MR technological devices (e.g., format, information and customisation) constitutes a flourishing area of academic investigation, including information science, and represents one of the main challenges for the ICT industry. It can support both developers and museum managers in exploring and exploiting the ergonomics of the MR technological devices and developing immersive experiences for museum exhibitions and organisations.

This paper aims to contribute to the academic and practitioner debate on the ergonomic role of the MR in the museum by investigating how and to what extent functional elements of MR devices affect diverse forms of immersive experiences in the museum and then drive visitors' post-experience behaviours.

A conceptual framework has been proposed, integrating the variables validated in preceding studies on the use, adoption and experiences driven by immersive realities in the museum. It tests the causal relationships between variables measuring functional elements of MR devices and immersive museum experiences and evaluates their effects on post-experience visitors' behaviours.

The paper has been structured as follows: The second section provides the theoretical background, including the critical debate on barriers and constraints of MR in the museum; the third section presents the conceptual model and the hypotheses development; the fourth section presents the research design; and the fifth section summarises the findings. Discussion and conclusion open new research scenarios, providing useful insights for theory formation and verification and managerial implications on the role of immersive museum experiences under the MR landscape and its influence on visitors' future behaviours.

2. Mixed reality in cultural heritage museums

Immersive technologies – including AR, VR and MR – have been investigated widely as digital environments that extend or replace the user's real surroundings, redesigning the real–virtual continuum phenomenon (Anderson *et al.*, 2020; Banerjee *et al.*, 2020; Bekele *et al.*, 2018; Daassi and Debbabi, 2021; Flavian *et al.,* 2019; Hudson *et al*., 2019; Suh and Prophet, 2018). As disruptive technologies, they constitute innovative information systems (IS) that overlay the real and virtual world, shifting the traditional tangible points of interaction in the virtual environment (Bekele *et al.*, 2018; Daassi and Debbabi, 2021; Flavián *et al.*, 2019; Hudson *et al.*, 2019).

VR and AR present different approaches in several aspects, including the user's immersion, the continuity between the real and virtual world and the sense of proximity and user's presence. VR recreates a virtual or imaginative world in which the user's bodily representation does not matter; rather, AR overlaps digital representation with the real world, rendering self-representation imperative for immersive experience (Daassi and Debbabi, 2021). As a cutting-edge generator of mediated surroundings, MR integrates AR and VR in a smart interface, using different technical features, such as visualisation, presence, interactivity and vividness (Bae et al., 2020; Bekele et al., 2018; Flavián et al., 2019; Hudson et al., 2019; Kang et al., 2020; Rokhsaritalemi et al., 2020).

Leveraging immersive technologies, cultural organisations (including museums) are exploiting technology-driven innovation to extend their mission and reshape the service model impacting on visitor's perception and experience (Cuni et al., 2015; Lee et al., 2020; Pallud, 2017; Trunfio *et al.*, 2022). Museums capitalise on immersive technology opportunities, experimenting with innovative ways to integrate the valorisation of preserved knowledge (historical collection) education and creative experiences (Lee et al., 2020; Pallud, 2017; Trunfio *et al.*, 2020).

MR plays a relevant role in museum innovation, leveraging unexplored visitor–technology–exhibition content interaction. It redefines the reality–virtuality continuum in a unique space–temporal environment, which reshapes physical, social and symbolic spaces (Bekele *et al.*, 2018; Flavián *et al.*, 2019; Rokhsaritalemi *et al.*, 2020; Trunfio *et al.*, 2020).

AR technologies lever on action–visualisation techniques to develop three-dimensional (3D) synthetic information in real time, such as images, videos and textual projections (Bekele *et al.*, 2018; Chung *et al.*, 2018; Cranmer *et al.*, 2020; He *et al.*, 2018; tom Dieck *et al.*, 2016; tom Dieck and Jung, 2017; Yung and Khoo-Lattimore, 2019). It creates museum–digital interactive content, enhancing the cultural heritage value in the context and proposing additional multimedia representations of historical or current real life (Bec *et al.*, 2019; Cranmer *et al.*, 2020; He *et al.*, 2018; Little *et al.*, 2020; Serravalle *et al.*, 2019; tom Dieck and Jung, 2018, 2017). AR introduces alternative forms of visualisation and interaction, allowing the visitor to visualise and interact with the immersive experience while remaining in the familiar real world (Bekele *et al.*, 2018; Oleksy and Wnuk, 2016; Trunfio *et al.*, 2020).

Complementarily, VR, exploiting computer-simulation techniques, enriches digital storytelling with illusory, inclusive and extensive information which promotes visitors' complete immersion and psychological presence into the multidimensional environment and socialisation with cultural heritage museum content (Bekele *et al.*, 2018; Guttentag, 2010; Kim *et al.*, 2020; Lee *et al.*, 2020; Manis and Choi, 2019; Tussyadiah, Wang, *et al.*, 2018).

In summarising, MR amplifies the traditional process of the museum visit, opening new opportunities to enrich and amplify visitors' experiential process with new interests, attention and engagement during the visit (Bae *et al.*, 2020; Trunfio *et al.*, 2020, 2022). Attracting non-expert visitors and new visitor profiles, MR fosters the cultural legacy and social memory and enhances cultural innovation (Bekele et al., 2018; Errichiello et al., 2019; Han et al., 2018; Jung et al., 2016; tom Dieck & Jung, 2017; Trunfio et al., 2020)

2.1 Mixed reality in the museum: technology requirements and immersive experiences

MR devices represent innovative but complex interfaces that combine diverse hardware, software and mobile computing with advanced techniques of visualisation – such as 3D, holograms, spatial mapping and sensors – to integrate museum cultural heritage exhibitions with digital and virtual content (Bekele, 2019; Bekele and Champion, 2019; Flavián *et al.*, 2019; Rahaman *et al.*, 2019). Advanced technological interfaces − with high levels of technical quality, comfort, usability, vividness and multimedia information − drive the value in the use of the MR devices and the value in the museum context of immersive experiences. The literature has emphasised the role of technological requirements and functional elements. They reflect the MR success by driving visitors to experience dynamic and autonomous forms of human-to-technology interaction with the museum, its contents and exhibitions (Ostrom *et al.*, 2015; tom Dieck *et al.*, 2016), resulting in a higher level of technological embodiment and perceptual presence in a hybrid environment.

AR and VR functional elements of the technological devices have been analysed by applying the theories of technological requirements and the technology acceptance model (TAM) (Chung *et al.*, 2015a; Davis, 1989; Jung *et al.*, 2015; tom Dieck and Jung, 2018) and the technology readiness and acceptance model (TRAM) (Lin and Chang, 2011). They regarded the following factors: hardware, software design, mobile computing devices (Bekele, 2019; Bekele and Champion, 2019; Rahaman *et al.*, 2019; Rokhsaritalemi *et al.*, 2020); technology acceptance and user intention (Manis and Choi, 2019; tom Dieck and Jung, 2018);

wearability and security requirements (Errichiello *et al.*, 2019; tom Dieck *et al.*, 2016; Tussyadiah, Jung, *et al.*, 2018); mapping, navigation and object-tracking (Kang *et al.*, 2020; Rokhsaritalemi *et al.*, 2020); interactive content and multimedia technical characteristics, such as audio, images, video and touch, which drive technical quality in the visualisation of immersive digital (Fenu and Pittarello, 2018; Javornik, 2016a, 2016b; Schaper *et al.*, 2018); and information presentation, personalisation and sharing (Han *et al.*, 2018; Jung *et al.*, 2015; tom Dieck *et al.*, 2016).

Amongst technological elements, the type of hardware and software implemented – as well as the synchronisation of the interactive and multimedia characteristics of AR and VR – represents critical aspects of designing authentic and innovative devices able to provide high levels of technical quality and capture the users' interest and time during the use (Trunfio *et al.*, 2020). Interactive and multimedia elements, such as audio, image, video and touch should be realised and installed, ensuring high levels of quality. Moreover, the design of these multimedia elements should be developed considering the device's size, building an authentic and original interface able to provide relevant information and enhancing users' involvement in new practices of information acquisition.

Other academics have investigated immersive museum experiences such as emotional gratification and enjoyment (Kim *et al.*, 2020; Lee *et al.*, 2020; Park and Stangl, 2020; tom Dieck and Jung, 2017; social and playful experiences combined in edutainment (He *et al.*, 2018; Tussyadiah, Wang, *et al.*, 2018); learning combined with heritage preservation and valorisation; heritage valorisation (Bec *et al.*, 2019; Little *et al.*, 2020), educational, entertainment, socialisation and escape (Trunfio and Campana, 2020).

Furthermore, recent research, which applies brand equity theory, revealed that the characteristics of MR (interactivity and vividness) not only influence the affective aspects (perceived immersion and perceived enjoyment) of visitors' experiences but also positively affect brand awareness, brand association and brand loyalty (Bae *et al.*, 2020), driving future behaviour.

2.2 Mixed reality in the museum: barriers and constraints

The existing literature has emphasised the value of MR in museums and cultural organisations (Jung and tom Dieck, 2017), but diverse limitations in acceptance, adoption and use of technological devices can be tracked in theoretical and practical-led papers. Various barriers to adoption and user experience have been identified, such as technological limitations, cultural content complexity and human factors (Bekele *et al.*, 2018). Overcoming technological limitations (e.g., sensor-based tracking, standardisation, user-driven semantics, tangible AR and fully immersive VR and multimodal interfaces) has been widely discussed in the literature (Bekele *et al.*, 2018). Technical specifications of the VR technologies, such as the stand-alone value of the market, represent an additional challenge (Laurell *et al.*, 2019).

Combining the techno- and user-centred perspectives, the ergonomic evaluation of MR offers diverse perspectives to interpret the use and constraints of the MR applications in museum organisations and other services. Ergonomic knowledge considers the issue of continuity which characterises the users' perceptual and cognitive fluidity between the real world and the virtual world (Bach and Scapin, 2004). As main implications, diverse limitations have been considered in MR adoption and use, related to the physical environment and the subjects using immersive realities.

Limitations associated with the physical environment concern the continuity between physical reality and VR (immersion and presence) and the human movements in space. Overcrowding in halls, rooms and bottleneck paths close to the point of interest (POI) disturbs other visitors who want a holistic perception of the cultural heritage and art without technological devices (Flavián *et al.*, 2019). People using wearable AR and VR technologies can create a distraction for other visitors and reduce their art appreciation naturally with a hands-free approach without the disturbance of devices; on the other hand, wearing an MR device and then taking it off when looking at paintings can amplify the distraction (tom Dieck *et al.*, 2016).

Besides, physical space (e.g., the temperature during the video projection), subject restrictions (e.g., use of gesture and voice) and other aspects (e.g., sudden environmental changes and the movement of the object) amplify the physical limitations of MR use (Rokhsaritalemi *et al.*, 2020).

As one of the main subjective limitations, VR sickness has been identified as a high-priority topic in the VR industry that has attracted academic investigations. Diverse forms of sickness (e.g., nausea, dizziness, eyestrain or headache) have been caused by hardware and content (optical flow, graphic realism, rendering reference frames and task-related features) or affected by human factors (age, gender and motion sickness history) (Hammady *et al.*, 2020; Liao *et al.*, 2020; tom Dieck *et al.*, 2016). Issues of privacy, security, confidentiality and informed consent represent additional and relevant limitations of MR technology application.

Lastly, the implementation of the digital innovation of the museum service model is still ongoing and requires significant financial and human investment (Trunfio *et al.*, 2022). The price/budget represents one concern motivating immersive technology adoption (Laurell *et al.*, 2019), including museum and cultural heritage. Immersive visitor–technologies–content interaction presents various constraints, including technology adoption, acceptance and use for both consumers and employees (Jung *et al.*, 2015; Rauschnabel and Ro, 2016; Solnet *et al.*, 2019; tom Dieck and Jung, 2018).

Organisational aspects and human resources training and management play a critical role in museum digital innovation; they can facilitate or hinder technological adoption, acceptance and use of AR and VR advanced interfaces and software for both visitors and museum organisations (Trunfio *et al.*, 2022).

2.3 Measuring mixed reality's impact on the museum experience

Although the literature has investigated MR technology requirements and immersive experiences in cultural organisations mainly separately (see section 2.1.), recent research has proposed a conceptual model for AR in urban heritage tourism, integrating functional and experiential elements (Han *et al.*, 2018). It has aimed to explore how a comprehensive set of AR product features (content, presentation, functionality and interaction) influence pragmatic and hedonic attributes of the users' experiences and satisfaction.

Building on previous AR and VR literature and introducing additional dimensions/items, a visitors' experience model for MR in the museum has been proposed and validated (Trunfio and Campana, 2020). The model identified the role of six functional dimensions – format, museum information, customisation, usability, interaction and information saving – and one experience dimension measured by the following five items: heritage valorisation, educational, entertainment, socialisation and escape (Trunfio, Campana, *et al.*, 2020).

Immersive technologies have reinvented museum experiences and accelerated the transformative processes of the museum's mission. Although museums continue preserving and celebrating the tangible and intangible heritage – with the purposes of education, study and enjoyment – digital technologies allow more comprehensive visitor experiences, which catalyse creativity, innovation and sustainable development (Falk & Dierking, 2016; ICOM-OECD, 2017). Trunfio et al.'s (2020) research identified two immersive experiences for museum visitors under MR conditions, "traditional experience" and "4.0 experience", by applying principal component analysis. This research identified traditional museum experiences in the MR environment as forms of heritage preservation and education facilitated by ten technological–functional elements of MR devices (e.g., museum information on the exhibition, historical period and city attractions or interaction with museum servicescape and multimedia elements) (Trunfio *et al.*, 2020). They represent museum learning experiences in which innovative multimedia features of MR enhance the heritage value, levering on emotional gratification and co-creation (Han et al., 2018; Pallud, 2017; Parong et al., 2020; tom Dieck, Jung, & tom Dieck, 2018; Trunfio et al., 2020).

However, 4.0 experiences have been identified as the combination between entertainment, socialisation and escape with the support of eight technological–functional elements (e.g., interaction with other technologies, accessibility using own mobile device, information saving on personal devices or museum platforms) (Trunfio *et al.*, 2020). They enhance the role of MR in creating innovative forms of amusement experiences in the museum, attracting a new type of non-expert visitor through playful content, which drives entertainment and escape (He et al., 2018; Trunfio et al., 2020).

3. Conceptual framework and hypothesis development

Building on the literature advances, this research proposes a conceptual framework integrating the consolidated literature on MR, which measured technological requirements and immersive experiences in museum and post-experience behaviour separately. Measuring technological requirements and their impact on immersive experiences and post-experience behaviour allows the identification of possible barriers and constraints in technology adoption and use (e.g., MR devices' format or interactivity). It tests how and to what extent the MR devices' technological functionalities influence diverse typologies of museum experiences and post-experience behaviour (Fig. 1).

Fig. 1. Conceptual framework.

The model has been built considering nine constructs proposed by the literature (references in Fig.1). Six constructs identify the functional dimensions of MR devices – format, museum information, customisation, usability, interaction and information saving – which have been measured by eighteen items (Bekele *et al.*, 2018; Chung *et al.*, 2015a; Fenu and Pittarello, 2018; Han *et al.*, 2018; He *et al.*, 2018; Javornik, 2016a, 2016b; Jung *et al.*, 2015; Schaper *et al.*, 2018; tom Dieck *et al.*, 2016; tom Dieck and Jung, 2018; Trunfio and Campana, 2020). Two constructs summarise traditional experience (items: heritage valorisation and educational) and 4.0 experience (items: entertainment, socialisation and escape) (Conti *et al.*, 2017; He *et* *al.*, 2018; Lee *et al.*, 2020; Loreiro et al., 2021; Pine and Gilmore, 1999; Trunfio *et al.*, 2020). One construct, measured by three items (i.e., increase the use of digital technologies, promote the museum as authentic and revisit the museum), describes behavioural effects (Chung *et al.*, 2015a; Jung *et al.*, 2016; Kim *et al.*, 2020; Wei *et al.*, 2019).

Thirteen hypotheses describe the casual relationships that connect functional elements of the MR devices with immersive museum experiences and post-experience behavioural effects to achieve the four research purposes. Eight hypotheses (H_1-H_7 and H_9) test the influence of the functional elements of the technological MR devices on museum experiences (first purpose); two hypotheses (H_{10} and H_{11}) explore the role of visitors' interaction on both traditional experience and 4.0 experience (second purpose); one hypothesis (H_8) investigates the causal relationship between traditional experience and 4.0 experience (third purpose); two hypotheses (H_{12} and H_{13}) measure if and how much traditional experiences and 4.0 experiences drive post-experience behavioural effects (fourth purpose).

3.1 The relationship between format and museum information

The format construct identifies the installation of cutting-edge devices that synchronise and upload in real-time different multimedia elements (2D or 3D images, videos or animated content, textual information) in a technology-mediated environment (Bekele *et al.*, 2018; Javornik, 2016a; Kounavis *et al.*, 2012; tom Dieck *et al.*, 2016; tom Dieck and Jung, 2018; Trunfio *et al.*, 2020). Four items can measure the format construct, considering various previous studies: audio, image and video accessible through a mobile device, and touch.

The literature has recognised the multimedia characteristics of the format as innovating the museum exhibition and organisation by creating immersive information and facilitating visitors' visualisation (Bekele *et al.*, 2018; Fenu and Pittarello, 2018; Kounavis *et al.*, 2012; Schaper *et al.*, 2018; tom Dieck *et al.*, 2016; Trunfio *et al.*, 2020). Multimedia characteristics enhance visitors' visualisation by providing accurate, relevant, complete, timely, consistent, hypertextual and upload information and digital storytelling (He *et al.*, 2018; Javornik, 2016a; Jung *et al.*, 2015; Kang *et al.*, 2020; tom Dieck *et al.*, 2016; tom Dieck and Jung, 2018).

Museum information concerns mainly the collection of monuments, paintings and artefacts and reproduced or replaced by multimedia characteristics (Fenu and Pittarello, 2018; Garau, 2014; Marty *et al.*, 2016; Schaper *et al.*, 2018). Recent literature has integrated museum information related to the heritage exhibition with information about the museum service organisation and the city attractions (Trunfio and Campana, 2020). Four items describe museum information building on the consolidated literature: heritage exhibition, services, historical period and city attractions.

Therefore, based on previous research, the study proposes the following hypothesis:

H_1. The format has a positive effect on museum information.

3.2 The relationships between museum information, customisation usability and interaction

The customisation construct describes the capability of technological multimedia interfaces to shape tailor-made information according to the visitors' desires, interests and expectations, creating quicker ways to visualise and explore the museum exhibition (Jung *et al.*, 2015; Kang *et al.*, 2020; Kounavis *et al.*, 2012; tom Dieck *et al.*, 2016; tom Dieck and Jung, 2018). The customisation construct summarises two items (Trunfio and Campana, 2020): personalised information and multiple-language capability.

The usability construct, as wearability of the device, combines usefulness, ease of use, comfort, innovativeness, resistance and security (Bekele *et al.*, 2018; Chung *et al.*, 2015; Jung *et al.*, 2015; Manis & Choi, 2019; tom Dieck & Jung, 2018; Trunfio & Campana, 2020). A recent work, combining the previous literature, considered usability a construct measured by three key items (Trunfio & Campana, 2020): comfort, a clever alternative to access information and easy to use.

The interaction in an immersive virtual environment has received wide attention in the recent literature, as related to advanced technological interfaces that extend human sensory, cognitive and motor functions in a technology-mediated environment (Bekele *et al.*, 2018; Bekele, 2019; Carrozzino and Bergamasco, 2010; Flavián *et al.*, 2019; Hudson *et al.*, 2019; Muhanna, 2015; tom Dieck and Jung, 2017; Trunfio *et al.*, 2020). Building on the literature investigating interaction in the digital environment of the experiences (Trunfio *et al.*, 2020; Wang and Xia, 2019), three items have been identified (Trunfio and Campana, 2020): servicescape, multimedia elements and other technologies.

Literature studies have assumed both customisation (tom Dieck *et al.*, 2016) and usability as drivers of interaction with museum physical content and digital storytelling (Ardito *et al.*, 2018), which facilitate involvement and immersion in the museum experience (Fenu & Pittarello, 2018; Flavián et al., 2019; Hudson et al., 2019; Jung et al., 2015; Kang et al., 2020; Not & Petrelli, 2018; tom Dieck & Jung, 2018; Trunfio et al., 2020).

Enhancing the level of customisation reduces some barriers (e.g., language) and allows going directly to satisfy the main interests in visiting a museum. By diminishing limitations in MR use, customisation boosts the interaction in the museum experience (e.g., with the preferred multimedia elements or with the museum servicescape).

Usability, as a technical aspect of MR devices, describes the capacity of a system to provide optimised use conditions. Improving usability elements, such as the comfort of the wearable device, reduces constraints and leads to a higher level of interaction (e.g., with the multimedia or physical–digital environment) and enhances the value of the immersive experience.

Consequently, the hypotheses raised here are as follows:

H_2. Museum information has a positive effect on customisation.

H_3. Museum information has a positive effect on usability.

H_4. Customisation has a positive effect on interaction.

H_5. Usability has a positive effect on interaction.

3.3 The relationships between interaction, traditional experience and 4.0 experience

Research studies have devoted significant attention to the immersive experiences in museums and cultural heritage. Edutainment represents a way to experience the museum through the technology by integrating different experiential elements (Addis, 2005; Antón *et al.*, 2018; Balloffet *et al.*, 2014; Svensson and Samuelsson, 2021), such as education and entertainment (Ardito *et al.*, 2018; Lee *et al.*, 2020; Trunfio *et al.*, 2020); learning and play; social and joyful (tom Dieck and Jung, 2017; He *et al.*, 2018)); escapism and joyless (Kang *et al.*, 2020).

Recent research has investigated diverse technology-driven museum experiences, ranging from traditional experiences to 4.0 experiences (Trunfio *et al.*, 2020). Traditional experiences in a technological environment combine heritage valorisation and education. In the MR environment, 4.0 experiences combine entertainment, socialisation and escape, proposing amusement visit forms that facilitate visitors' immersion and socialisation with the heritage (Conti *et al.*, 2017; He *et al.*, 2018; Trunfio *et al.*, 2020).

Considering museums as information-intensive institutions, the interaction in the immersive environment provides a dynamic variety of visitors' experiences. Interaction facilitates alternative ways to learn diverse forms of culture and reduce heritage exploitation (Bec *et al.*, 2019; Guttentag, 2010; Hall and Bannon, 2006; Little *et al.*, 2020; Pallud, 2017; Parong *et al.*, 2020; tom Dieck *et al.*, 2016; tom Dieck and Jung, 2017; Trunfio *et al.*, 2020). Pallud (2017) identified interactivity as a significant predictor of cognitive engagement, which drives learning and education in the immersive environment. Connecting interaction with immersion in the digital domain, Cuni et al. (2015) described the optimal experience in which individual skills and interaction have been balanced.

The research assumes interaction as a driver of diverse experiences in the museum's immersive environment, ranging from the "first preoccupation of the museum" (e.g., learning/education; Pallud, 2017) to advanced immersive experiences, which the 4.0 industry has transformed. Besides, investigating if and how much traditional museum experience under MR conditions can influence other 4.0 experiences remains a flourishing area of investigation.

Levering on the previous literature, the study forms the following hypotheses:

H_6. Interaction has a positive effect on the traditional experience.
H_7. Interaction has a positive effect on the 4.0 experience.
H_8. Traditional experience has a positive effect on the 4.0 experience.

3.4 The relationships between interaction, information saving, traditional experience and 4.0 experience

Information saving is a debated area of investigation due to security and privacy issues connected to storing of sensitive information on smartphones and social networks (Guzman, 2019; Han *et al.*, 2018; tom Dieck *et al.*, 2016). Previous research identified information saving as a social functionality intrinsic in mobile applications that sparks and empowers the visitors' enthusiasm and behaviour (Han *et al.*, 2018; Hudson *et al.*, 2019; tom Dieck and Jung, 2018, 2017). Using museum platforms, visitors create self-generated digital content as gifts, photos and videos; they are allowed to share them on museum social networks, web pages, forums, and blogs, participating in active museum communication and attracting current and new visitors (Antón *et al.*, 2018; Han *et al.*, 2018; Hudson *et al.*, 2019; Jung and tom Dieck, 2017). Visitors can also connect the MR interface to personal devices (Trunfio and Campana, 2020), engaging friends and relatives in the direct sharing of digital storytelling content (Yoo & Gretzel, 2011) and stimulating their imagination to live the same experiences (Antón *et al.*, 2018) in terms of enjoyment and memorability (Dong and Siu, 2013; Lee *et al.*, 2020). The construct of information saving can be measured by two items (Trunfio and Campana, 2020): personal devices and museum platforms.

The use of information saving increases visitors' satisfaction and the museum's experiential value (Antón *et al.*, 2018; Hudson *et al.*, 2019; tom Dieck *et al.*, 2016; Trunfio *et al.*, 2020;

Yoo and Gretzel, 2011). It reinforces the perception to be an integrative part of heritage homage and the social awareness process, with feeling based on the educational, entertainment and socialisation experiences (Bec *et al.*, 2019; Little *et al.*, 2020; Trunfio *et al.*, 2020). Levering on the previous literature, the study forms the following hypotheses:

H9. Interaction has a positive effect on information saving.
H10. Information saving has a positive effect on the traditional experience.
H11. Information saving has a positive effect on the 4.0 experience.

3.5 The relationships between traditional experience, 4.0 experience and behavioural effects

Immersive technology-driven experiences lead museum visitors towards positive reactions, attitudes and behaviours (Jung et al., 2016; Jung et al., 2018; Kim et al., 2020; Lee et al., 2020; Tussyadiah, Wang, et al., 2018). Amongst the several post-experiential reactions investigated in the literature, the increasing use of new digital technologies, the promotion of the museum as authentic and revisiting the museum have been identified as crucial items in some preliminary empirical studies (Chung et al., 2015; Jung et al., 2016; Kim et al., 2020; Lee et al., 2020; Tussyadiah, Wang, et al., 2018).

The increasing use of innovative digital technologies in cultural organisations represents a flourishing research area of consumer/user behaviour. The literature has investigated how positive aspects of the immersive technologies (e.g., quality of AR mobile application; complete access to museum contents by exploiting AR and VR opportunities) drive intentions to reuse digital technologies (Daassi and Debbabi, 2021; Chung et al., 2015; Jung et al., 2016). Measuring if and how much immersive museum experiences can affect the visitors' desire to reuse digital technologies can offer opportunities to reshape the museum mission and innovate exhibitions and content by combining diverse technologies.

Promoting the museum as authentic under MR conditions represents an additional behavioural effect that covers a challenging investigation area in the immersive experience domain. The controversial and multidimensional construct of brand authenticity has been investigated from several perspectives; scales measuring quality commitment, heritage and sincerity have been proposed (Napoli et al., 2014).

MR application in the museum is questioning the concept of authenticity. MR reshapes the virtual–real continuum in museum experiences by combining VR with the augmentation of the museum as both physical content (e.g., monuments and exhibitions) and the context in which experiences occur. Consequently, experiencing culture (e.g., museums, monuments and archaeological sites) in an AR-generated environment blurs the boundaries between existing preserved heritage and imaginative spaces.

The literature has considered the positive effects of visitors' immersive experiences, such as (Bae *et al.*, 2020; Chung *et al.*, 2015b; Lee *et al.*, 2020) the awareness of the technology's role to combine new museum experiences with heritage preservation for the next generation. Thus, the enhancement of the museum image is authentic and iconic. If and how the positive MR experiences allow visitors to perceive and promote a museum as authentic remains a crucial question, requiring deeper investigation as further research streams and business issues for museums and other organisations.

Revisiting the museum as post-experience effect presents relevant interest for museum managers. A positive museum image is a critical factor to stimulate visitors' attachment to the museum (Kim *et al.*, 2020), influencing their behavioural intention to re-experience the museum with a new future visit (Lee *et al.*, 2020; Tussyadiah, Wang, *et al.*, 2018; Wei *et al.*, 2019).

Based on the previous literature, the study forms the following hypotheses:

H_{12}. Traditional experience has a positive effect on behavioural effects.
H_{13}. Experience 4.0 has a positive effect on behavioural effects.

4. Research design

4.1 Study context

An on-site survey was conducted in an Italian cultural heritage museum in the historical city of Rome. The museum is interested in the physical presence of an important Roman art masterpiece and a specific MR project. The project combines AR and VR technologies in a Samsung Gear VR viewer paired with a Samsung S7 smartphone.

The MR project introduces access to multi-sensorial and multi-dimensional representations of the Roman monument, rebuilding its culture and historical value in nine POIs. Amongst the nine POIs, POI 1 and POI 2 combined film visualisation techniques and VR technology to create a 360-degree video, rebuilding and illustrating the authentic and historical colours of the monument. POI 3 provided access to the historical period and atmosphere of the monument, offering a 3D flying-view visualisation of the historical area in which the monument was located. Finally, POIs 4 to 7 operated using a 3D tracking system based on advanced computer-vision algorithms (photogrammetry and structure sensor with Skanect 3D scanning software) to recognise the monument's three-dimensional bas-reliefs and overlay the physical heritage surface with augmented information in real time.

The MR project has been designed to experiment with innovative practices of exhibition visualisation and interaction that leave untouched the cultural heritage of Roman history, preserving and valorising its value. The MR allows a physical experience in the cultural heritage museum which integrates the physical museum exhibition (e.g., monument) with diverse immersive historical content (Fig. 2).

Fig 2. MR experience in the cultural heritage museum.

Combining AR and VR technologies, the project facilitates the immersive learning experience of the Roman cultural heritage museum combined with ancient Roman habits, traditions and rituals. AR technologies allow the reconstruction of the original colours of the monument (Fig. 3).

Fig. 3. AR reconstruction of the monument’s original colours.

In addition, the VR experience allows the engagement of visitors in an ancient Roman sacrificial ritual, recreating the context and the people (Fig. 4).

Fig. 4. VR experience of an ancient Roman sacrificial ritual.

The project combines heritage enhancement practices with learning and entertainment elements, enriching cultural experience with strong emotional values.

4.2 Measurements

A survey questionnaire was adopted considering multi-measurement items validated from prior studies (Churchill, 1979). It included twenty-six items summarised into nine constructs (Table 1). Six technological–functional constructs were measured by eighteen items: format (four items), museum information (four items), customisation (two items), usability (three items), interaction (three items) and information saving (two items). Two immersive museum-experience constructs were measured by five items: traditional experience (two items), 4.0

experience (three items). Finally, one behavioural-effect construct was measured by three items.

Table 1. Measurement model.

Multiple items measured each construct. This setting overcame the limitation of a single measurement item, considered too specific to capture the attribute of a construct and remove each possible measurement error in tests of hypotheses (Bagozzi and Yi, 2012).

All multi-measurement items were designed using a seven-point Likert-type scale ranging from (1) strongly disagree to (7) strongly agree (Joshi *et al.*, 2015). A seven-point Likert-type scale was adopted to get clear and unambiguous scores that optimised the reliable, valid and discriminating power for the twenty-six items (Preston and Colman, 2000; Symonds, 1924). Moreover, six sociodemographic variables were included to collect information on the visitors' country, gender, age, qualifications and job position.

The multi-measured model has been identified following four steps. The first step investigated existing items in the literature measuring MR (including AV and VR) functional elements, experiences and post-experience behaviours. Trunfio and Campana's (2020) visitors' experience model for MR in the museum was considered to measure functional and experience items.

During the second step, each item of Trunfio and Campana's (2020) model has been validated considering additional literature on technological–functional items (Bekele *et al.*, 2018; Chung *et al.*, 2015a; Fenu and Pittarello, 2018; Han *et al.*, 2018; He *et al.*, 2018; Javornik, 2016a, 2016b; Jung *et al.*, 2015; Schaper *et al.*, 2018; tom Dieck *et al.*, 2016; tom Dieck and Jung, 2018; Trunfio and Campana, 2020)and immersive museum experience items (Conti *et al.*, 2017; He *et al.*, 2018; Lee *et al.*, 2020; Pine and Gilmore, 1999; Trunfio *et al.*, 2020; Trunfio and Campana, 2020). Additional literature has been investigated to identify the three items of the post-experience behavioural effects (Chung *et al.*, 2015a; Jung *et al.*, 2016; Kim *et al.*, 2020; Lee *et al.*, 2020; Wei *et al.*, 2019).

During the third step, the measurements were successfully validated with a double-blind review process by two managers (Chenail, 2011), experts in the study topic and MR application designers in tourism and cultural heritage. Finally, during the fourth step a pilot test was performed (Chenail, 2011), administering the questionnaire to 30 casual museum visitors to identify and replace ambiguous content expressions. The description of the items was designed by two native English speakers.

4.3 Data collection

A sample of 312 museum visitors experiencing the MR project from September to December 2019 was involved in the research. Five trained interviewers supported visitors in three phases (before, during and after the visit) in order to explain diverse aspects of the museum and the use of the devices, reducing bias in completing the survey; they collected data before and after the visit.

Before the visit, five interviewers positioned at the museum entrance informed visitors of the research goal, asking if they were willing to participate in the study. The interviewers provided a Samsung Gear VR viewer paired with a Samsung S7 smartphone and technical instructions on the MR use and the different functionalities installed in the device for each visitor participating. In addition, visitors received specific information on the nine POIs installed in the museum exhibition, distinct for MR, AR and VR. During the museum visit, five interviewers checked visitors' exploration and interaction with the exhibition. After the visit, the five interviewers administered the questionnaires face-to-face, collecting data on visitors participating in the research project.

4.4 Data analysis

The study examined the conceptual framework and related hypotheses, employing a covariance-based structural equation modelling (CBSEM) analysis with a maximum-likelihood (ML) method using the eighth version of linear structural relationships (LISREL) software (Jöreskog, 1967, 1973; Jöreskog and Sörbom, 1982).

Following the literature (Bagozzi and Yi, 2012; Fornell and Bookstein, 1982; Hair Jr. *et al.*, 2017; Reinartz *et al.*, 2009), the ML-based CBSEM was selected as a serious and rigorous empirical research method. The following reasons supported the choice. Firstly, an ML-based CBSEM is a research method extremely robust in identifying violations of its underlying distributional assumptions, even in extreme cases of skewness and kurtosis (Bagozzi and Yi, 2012; Hair Jr. *et al.*, 2017; Reinartz *et al.*, 2009). It requires normally distributed and interval-scaled variables to create more consistency and accuracy in the estimated parameters (Fornell and Bookstein, 1982). Secondly, an ML-based CBSEM analyses only latent variables measured by reflective items (Bagozzi and Yi, 2012; Jarvis *et al.*, 2003; Shah and Goldstein, 2006), reflecting high internal consistency and reliability and sharing a common variance (MacKenzie *et al.*, 2005). Thirdly, an ML-based CBSEM requires a minimum sample of 20 to avoid convergence problems and improper solutions (Boomsma and Hoogland, 2001; Fornell and Bookstein, 1982). Fourthly, an ML-based CBSEM is a useful method to confirm and validate extensively investigated and appropriately developed theoretical models, demonstrating theoretically assumed relationships (Bagozzi and Yi, 2012; Reinartz *et al.*, 2009). Last, it estimates a set of model parameters reproducing a theoretical covariance matrix as close as possible to the empirical covariance matrix observed within the estimation sample (Bagozzi and Yi, 2012; Ullman and Bentler, 2013).

Harman's (1967) single-factor test, as the main post hoc statistical procedure (Tehseen *et al.*, 2017), was used in this study to assess and control the potential presence or absence of a common method variance (CMV) in the measurement model. All investigated items were subjected to exploratory factor analysis (EFA) with eigenvalue >1 to reveal a potential single factor accounting for more than 50% of the variable's variance. The EFA output revealed that all twenty-six investigated factors accounted for 76.66% of the total variance. Specifically, the first unrotated factor captured only 23.19% of the total variance in data, followed by the subsequent factors (10.30%, 8.74%, 8.43%, 7.59%, 6.81%, 5.99% and 5.58%). Accordingly, the first factor was below the recommended 50% threshold, indicating that CMV was not an issue in this study (Chang *et al.*, 2010; Tehseen *et al.*, 2017).

5. Findings

5.1 Profile of the sample

The study profiled visitors experiencing the MR project in Table 2. The majority of the respondents had an Italian profile (67.3%), followed by other foreigners (32.7%). Over half of the participants were female (51.2%), and the age group most representative was 20–29 years old (33.1%), followed by 30–39 (27.4) and 40–49 (18.7%). Visitors with a university degree prevailed (43.7%), and more than half of the visitors were students (53.7%).

Table 2. Visitor profiles.

5.2 Measurement model

Before the structural model estimation, the study evaluated the adequacy of the measurement model in three steps. The first step examined the convergent and divergent validity of twenty-six items (Bhattacherjee and Sanford, 2006). Each factor loading exceeded the .5 value, indicating that no construct items shared high levels of residual variance with other constructs (Table 3). Therefore, multi-measurement items' convergent and divergent validity were satisfied (Fornell and Larcker, 1981).

The second step tested the measurement model analysing the structure's reliability at the construct level (Tables 3 and 4). Cronbach's alpha (α) and composite reliability (CR) estimated the internal reliability of the reflective items for each construct (Bagozzi and Yi, 2012; Churchill, 1979; MacKenzie *et al.*, 2005). Cronbach's alpha coefficient was adopted as the best indicator of the ML-based CBSEM method to measure the construct's appropriateness by analysing each item's internal consistency, attributing to all different items an equal weight (Bagozzi and Yi, 2012; Churchill, 1979). CR provides a thorough evaluation of all items within a single construct, analysing the weight of each item (Bagozzi and Yi, 2012; Chin, 1998; Churchill, 1979). Both indicators defined all measured constructs as reliable and greater than 0.7 (Bagozzi and Yi, 2012; Chin, 1998; Churchill, 1979; MacKenzie *et al.*, 2005).

The third step was the performance of the average variance extracted (AVE) to analyse the convergent and divergent validity of the measurement model (Churchill, 1979; Hair *et al.*, 2010). It exploited standardised factor loadings to evaluate a positive correlation amongst all construct items that shared a high common proportion of variance. All constructs were deemed acceptable because their AVE was higher than .50 (Table 3) (Churchill, 1979; Fornell and Larcker, 1981; Hair *et al.*, 2010). Additionally, the explanatory power of the individual constructs was also evaluated through the R2 showing excellent results. The test focused on the intra-correlations amongst all constructs. It used the square root of AVE values in Table 3, validating all diagonal elements as being greater than the corresponding off-diagonal elements (Table 4).

Table 3. Reliability and factor loadings.

Table 4. Correlation and discriminant validity (standardised values).

5.3 Structural model

Next, we performed an ML-based CBSEM using LISREL 8 software to test the measurement model's latent structural model (Bagozzi and Yi, 2012; Jöreskog and Sörbom, 1996). As shown in Figure 4 and summarised in Table 5, the latent structural model was composed by one gamma parameter ($\gamma_1 = H_1$) and twelve beta parameters ($\beta_1 = H_2$, $\beta_2 = H_3$, $\beta_3 = H_4$, $\beta_4 = H_5$, $\beta_5 = H_6$, $\beta_6 = H_7$, $\beta_7 = H_8$, $\beta_8 = H_9$, $\beta_9 = H_{10}$, $\beta_{10} = H_{11}$ and $\beta_{11} = H_{12}$). The estimation of the latent structural model drove the support of twelve hypotheses, except for H_{13}

(experience 4.0 has a positive effect on behavioural effects). Moreover, four out of twelve hypotheses assumed an extremal statistical significance: $\beta_2 = H_3$ (museum information has a positive effect on usability), H_9 (interaction has a positive effect on the traditional experience), $\beta_{10} = H_{11}$ (traditional experience has a positive effect on the 4.0 experience), and $\beta_{11} = H_{12}$ (traditional experience has a positive effect on behavioural effects).

Hypothesis testing deemed the format construct had a significant effect on the museum information construct ($\gamma_1 = .18$, *p-value* < .001). The museum information construct had a dual significant effect on both the constructs of customisation ($\beta_1 = .15$, *p-value* < .0025) and usability ($\beta_2 = .26$, *p-value* < .0001). The customisation construct had a significant effect on the interaction construct ($\beta_3 = .17$, *p-value* < .0025). The usability construct had a significant effect on the interaction construct ($\beta_4 = .13$, *p-value* = .01). The interaction construct had a dual significant effect on both the constructs of traditional experience ($\beta_8 = .33$, *p-value* < .0001) and 4.0 experience ($\beta_9 = .14$, *p-value* < .01). The construct of information saving played a mediation role, receiving a significant effect from the interaction construct ($\beta_5 = .13$, *p-value* < .01) and influencing significatively both the constructs of traditional experience ($\beta_6 = .20$, *p-value* < .001) and 4.0 experience ($\beta_7 = .12$, *p-value* < .02). The construct of traditional experience had a significant effect on the 4.0 experience construct ($\beta_{10} = .44$, *p-value* < .0001). The construct of information saving played a mediation role, receiving a significant effect from the interaction construct ($\beta_5 = .13$, *p-value* < .01) and influencing significatively both the constructs of traditional experience ($\beta_6 = .20$, *p-value* < .001) and 4.0 experience ($\beta_7 = .12$, *p-value* < .02). Finally, the construct of behavioural effects was significantly affected by the construct of traditional experience ($\beta_{11} = .26$, *p-value* < .0005) but not by the construct of the 4.0 experience ($\beta_{12} = .08$, *p-value* = .2900).

Fig. 5. Conceptual framework estimation.

Table 5. Summary of hypothesis testing.

5.4 The evaluation model goodness of fit

Three classes of goodness of fit (GOF) examined the evaluation model goodness in Table 6 (Bagozzi and Yi, 2012; Jöreskog and Sörbom, 1996): absolute fit indices, incremental fit indices and parsimonious fit indices.

Absolute fit indices were determined by $\chi 2$ testing to evaluate the discrepancy between the sample and the proposed model, requiring a probability larger than .05 (Bagozzi and Yi, 1988;

Hair Jr. *et al.*, 1998). Technically, $\chi 2$ is sensitive to sample size, becoming difficult to achieve satisfactory models, such as through increased sample size (Bagozzi & Yi, 2012). Therefore, the study combined $\chi 2$ testing with degrees of freedom to create a ratio that indicated a good fit with values ≤ 3. Absolute fit indices indicated a good model fit with $\chi 2 = 688.54$, d.f. = 286, and $\chi 2$/d.f. = 2.40, significant at $p < .001$. Additionally, the study investigated other statistical absolute fit indices to deepen if the estimated theoretical assumptions fit the real world (Bagozzi & Yi, 1988; Bollen, 1989; Hair Jr. et al., 1998; Jöreskog, 1993), including the root mean square error of approximation (RMSEA = .067), standardised root mean square residual (SRMR = .10), goodness-of-fit index (GFI = .90) and adjusted goodness of fit (AGFI = .82). These indices reflected an acceptable fit, assuming an absence of substantial approximation errors and potential differences between observed and predicted correlation matrices (Bagozzi & Yi, 2012; Hair et al., 2010; Jöreskog & Sörbom, 1996).

Incremental fit indices – comparative (Miles and Shevlin, 2007) or relative (McDonald and Ho, 2002) compared the $\chi 2$ value with that of the null model generated by the LISREL 8 software (Anderson and Gerbing, 1984; Hu and Bentler, 1999; Shumacker and Lomax, 2004; Tucker and Lewis, 1973). These were normed fit index (NFI = .90), non-normed fit index (NNFI = .93), relative fit index (RFI = .90), comparative fit index (CFI = .93) and incremental fit index (IFI = .93). Last, parsimonious fit indices evaluated the complexity of the estimated model with the parsimony goodness-of-fit index (PGFI = .70) and the parsimony normed-fit index (PNFI = .80) (Bagozzi and Yi, 1988, 2012; Mulaik *et al.*, 1989). Results indicated an acceptable fit with a simple model that did not require a delete process of items or constructs (Bagozzi and Yi, 1988, 2012; Mulaik *et al.*, 1989).

Table 6. Summary of fit goodness.

6. Discussion

Identifying the critical ergonomic aspects of the MR and measuring how the functional elements of the technological devices can enhance (or reduce) the value of visitors' experience and influence the post-experience behaviour remains a grey area of research. Shedding light on these aspects can help developers design IS with a higher level of effectiveness.

Confirming twelve hypotheses, except for one (H_{13}), the findings demonstrate the positive causal relationships between single elements of the MR devices and the museum experience and visitors' post-experience behaviour, which received academic investigation separately. It confirms the disruptive role of cutting-edge immersive technologies in museum innovation.

By levering on the combination of diverse ergonomic elements, MR in the cultural museum enhances the value of traditional experience (heritage valorisation and education) and 4.0 experience (entertainment, socialisation and escape) and drives visitors' post-experience behaviour.

This paper contributes to the debate on the application of ergonomics in museums achieving four purposes. Firstly, it demonstrates how the single functional element of the technological MR devices drives museum immersive experiences. Findings identify positive causal relationships between format, museum information, customisation, usability, interaction and saving information, which reshapes cultural propositions and innovates museum exhibition and organisation.

The research confirms key topics consolidated in the literature. The format represents a multimedia combination that experiments with innovative modalities involving visitors' interests with tailored information (customisation) and user-friendly interfaces (usability) (Jung *et al.*, 2015; Schaper *et al.*, 2018; tom Dieck *et al.*, 2016; tom Dieck and Jung, 2018; Trunfio *et al.*, 2020)**.** Measuring the functional requirements from a visitor's point of view (Bekele *et al.*, 2018; Laurell *et al.*, 2019; tom Dieck *et al.*, 2016) suggests that enhancing the quality of the design and the implementation of the MR devices in the museum can help in overcoming barriers in acceptance, adoption and use of the technological devices.

Secondly, the research identifies the interaction construct as a bridge connecting MR technological–functional constructs (format, museum information and customisation usability) and immersive museum experiences. Multimedia characteristics that enhance visitors' visualisation and digital storytelling drive visitors' interaction and drive new forms of immersive experiences (He *et al.*, 2018; Javornik, 2016a; Jung *et al.*, 2015; Kang *et al.*, 2020; tom Dieck and Jung, 2018).

Interaction – as advanced technological interfaces that extend human sensory, cognitive and motor functions in a technology-mediated environment – influences diverse experiences (Bekele *et al.*, 2018; Flavián *et al.*, 2019; Hudson *et al.*, 2019; Muhanna, 2015; Trunfio and Campana, 2020). The higher *t*-values of the causal relationship between interaction and traditional experience demonstrate how by enhancing interaction in MR experience, visitors can appreciate heritage valorisation and education. The research confirms that advances in MR technological elements empower the museum's mission of heritage valorisation and education. The interaction with museum servicescape, multimedia elements and other technologies creates positive effects on new and immersive forms of cultural experience, namely the 4.0 experience (entertainment, socialisation and escape), but with lower *t*-values.

Thirdly, presenting higher *t*-values, the findings demonstrate the key role of the museum immersive heritage valorisation and education in enhancing the value of 4.0 experiences, such as entertainment, socialisation and escape. It draws engaging scenarios on how the combination of cultural heritage and MR technological devices can transform the museum into a multimedia re-creational and easy-to-absorb knowledge environment. An innovative, multi-experiential context stimulates new forms of learning and entertainment and facilitates additional experiences in the museum (Antón *et al.*, 2018; He *et al.*, 2018; Lee *et al.*, 2020; Radder and Han, 2015; Svensson and Samuelsson, 2021; Trunfio *et al.*, 2020, 2021; Trunfio and Campana, 2020).

Causative relationships between museum immersive experiences and post-experience visitors' behaviour have been confirmed but present divergent results. As the confirmation of hypothesis H_{12} (traditional experience has a positive effect on behavioural effects) and the rejection of hypothesis H_{13} (experience 4.0 has a positive effect on behavioural effects) suggested, heritage valorisation and education under MR conditions continue to be driving forces of visitors' behaviours.

Heritage valorisation and education in an immersive MR environment trigger behavioural effects, supporting the previous literature on how learning elements influence visitors' intentions after experiencing immersive technologies (Jung *et al.*, 2016). Traditional experience has a high positive impact on three diverse visitors' behavioural effects: firstly, it increases the use of new digital technologies to acquire more information and make an informed decision (Chung *et al.*, 2015b; Lee *et al.*, 2020); secondly, it promotes the museum as authentic, through a heritage value (uniqueness, originality and iconicity), creating memorable and immersive experiences (Campos *et al.*, 2016; Kim *et al.*, 2020; Wei *et al.*, 2019); and thirdly, it creates an attachment to the museum and enhances the desire to revisit the museum (He *et al.*, 2018; Kim *et al.*, 2020).

Although museum 4.0 experiences represent one of the main challenges for museum innovation, findings show that entertainment, socialisation and escape (4.0 experience) do not affect visitors' future behaviours. There is a shift here away from the previous literature on the role of entertainment and escape as experiences that stimulate visitors' future behaviours (Jung et al., 2016). The research suggests that when historical and cultural heritage content prevails in the museum exhibition and experience, visitors consider MR a facilitator of traditional heritage valorisation and education.

7. Conclusion

Although the prevailing literature emphasised several advantages of using MR in the museum and cultural organisation experiences, implementing ergonomic solutions which enhance the value of the digital innovation of the museum is still ongoing. Exploring how the diverse functional elements of MR technological devices can influence both visitors' experiences in the museum and their post-experience behaviours, including the desire to revisit the museum, represents one of the main challenges for academics, managers and policymakers.

This research provides fresh knowledge in the museum innovation debate about MR conditions, proposing an overall conceptual model that integrates diverse angles of the phenomenon investigated separately. It presents and tests the causal relationships between ergonomic constructs of MR devices and immersive museum experiences and post-experience behaviours. Testing the constructs of the model, the paper draws and confirms the causal relationship between the single MR technological requirement and museum immersive experiences and visitors' post-experience behaviour.

The novelty of this research lies in bridging two main research gaps in MR investigation: the causal relationship between functional technological device elements and the museum experiences and the behavioural effects. Firstly, it demonstrates unexplored causal relationships between the functionality of MR devices and museum experiences, which represent two key aspects of MR research investigated separately. Secondly, the paper introduces a new perspective to evaluate post-experience behaviour, following MR experiences in the context of the museum, which combines the authenticity of the cultural heritage with the value in the use of digital technologies. The research measures the post-experience behaviours, adopting a variable investigated in previous studies (intention to revisit the museum) with new variables such as promoting the museum as authentic and increasing the use of digital technologies in other business contexts.

The research confirms that MR advances empower the museum's mission of heritage valorisation and education, which drive new immersive experiences and behaviours. The novelty resides in post-experience behaviour consistent with the cultural heritage museum mission (authenticity) and the value of immersive technologies (to increase the use of digital).

The paper offers new insights into the role of MR in reshaping cultural value propositions and redefining physical–virtual interaction between visitors and museums. In addition, it introduces insights to overcome technological limitations as a flourishing area of research investigation and a challenge for practitioners, including in the IS domain.

7.1 Theoretical contributions

The research provides academics with useful insights into MR theory building regarding the characteristics, functions and roles of technological devices affecting diverse, immersive experiences in several organisations (including museums) and driving visitors' post-experience behaviours. It draws on several theoretical advances to contribute to the debate on MR and other immersive technologies and their limitations. Also, it opens room for further academic investigations into the role of multimedia characteristics in experimenting with innovative physical–digital exhibitions and reinterpreting the human–technology interaction in cultural contexts.

This paper bridges several research gaps in MR investigation, demonstrating unexplored causal relationships between the functionality of MR technological devices and various museum experiences and post-experience visitors' behaviours, which have been investigated separately. It introduces insights to overcome technological limitations in debate, which represents the main challenge for practitioners and constitutes a flourishing area of investigation, including in the IS area of research.

Little attention has been devoted to how low functionality/effectiveness of the technological devices can raise barriers, limitations and constraints in users' perception of the immersive experiences. As with the precedent IS research, this study adopted a user-centred rather than a technology-centred approach, which has been recognised as more suitable to evaluate users' perceptions and reactions in an immersive environment.

Barriers, limitations and constraints are effects of the MR devices' design and effectiveness. The research suggests insights into the cultural heritage domain, shedding light on how technological advances can affect users' experience in the immersive environment, contributing to IS investigation. Measuring functional elements of the MR devices can improve the IS design enhancing experience and satisfaction.

The research corroborates the value of integrating diverse functional elements of the technological devices (format, museum information, customisation, usability, interaction and saving information) in building a museum as a multi-experiential context that combines traditional experiences (education and heritage valorisation) with 4.0 experiences (entertainment, socialisation and escape) (Bec *et al.*, 2019; Bekele *et al.*, 2018; Chung *et al.*, 2015a; Fenu and Pittarello, 2018; Flavián *et al.*, 2021; Guttentag, 2010; Jung *et al.*, 2015; Loreiro et al., 2021; tom Dieck *et al.*, 2016; Trunfio *et al.*, 2020).

The paper calls for more applied research that tests causal relationships between elements of MR technology to reduce barriers in adoption and use and enhance the market's stand-alone value(Laurell *et al.*, 2019). The ergonomic value of technological requirements can represent an additional scenario to test the cybersickness in the museum experience.

The study underlines the central role of the interaction – as a psychological state of flow, presence and immersion − between the museum's physical and multimedia spaces in the MR experience (Flavián *et al.*, 2019; Hudson *et al.*, 2019; Kang *et al.*, 2020; Trunfio and Campana, 2020; Wang and Xia, 2019). The museum can capitalise on advanced human–technology interaction to enhance its contents and exhibitions (Ostrom *et al.*, 2015) and create new forms of experiences. By extending the sensory, cognitive and motor functions of people in a technology-mediated environment, interaction reshapes experiences in the immersive museum spaces (Bekele, 2019; Bekele *et al.*, 2018; Carrozzino and Bergamasco, 2010; Flavián *et al.*, 2019; Hudson *et al.*, 2019; Muhanna, 2015; tom Dieck and Jung, 2017).

The major contribution is grounded in the museum's immersive experiences, multifaceted area of investigation (Guttentag, 2010; Han *et al.*, 2018; Lee *et al.*, 2020; Pine and Gilmore, 1999; tom Dieck *et al.*, 2018; tom Dieck and Jung, 2017; Trunfio *et al.*, 2020; Tussyadiah, Wang, *et al.*, 2018). This research presents unexpected but valuable theoretical contributions concerning the effectiveness of MR in enhancing diverse forms of immersive experiences in the museum, which advance the academic debate on immersive experiences in the cultural heritage museum.

The paper reveals that traditional museum experiences, heritage valorisation and education continue to play a dominant role in the MR cultural heritage museum experience and post-experience behaviours. It demonstrates how the combined value of the heritage valorisation and the education creates multimedia re-creational and easy-to-absorb content that stimulates a new form of learning and entertainment based on new skills, interests and attitudes towards the heritage (Addis, 2005; Garau, 2014; Komarac *et al.*, 2020; Radder and Han, 2015; Svensson and Samuelsson, 2021; tom Dieck and Jung, 2017). These multimedia-enhanced experiences drive positive effects on the correlates of entertainment, escape and socialisation.

Moreover, the MR value in creating immersive heritage valorisation and education has also been demonstrated, considering the positive effects on visitors' post-experience behaviour. The combined effects of the immersive experiences, which represent the facilitators of the traditional heritage valorisation and education, not only promote the museum as authentic (Campos *et al.*, 2016; Kim *et al.*, 2020; Wei *et al.*, 2019) and enhance the desire to revisit the museum (He *et al.*, 2018; Kim *et al.*, 2020) but also build positive attitudes towards the adoption of immersive technologies.

7.2 Managerial implications

This study has various implications and challenges for advances in immersive experience design. As the first managerial implication for the wider IS research, the paper suggests looking at the design of the ergonomic characteristics enhancing the value of the use of technological devices. Designing and implementing user-driven technological interfaces can facilitate interaction in an immersive environment, boost the value of innovative experiences and influence behaviours (prior to, during and post-experience).

However, MR implementation in the museum is a complex process that requires constant monitoring to ensure high levels of visitor interaction during its use. Enhancing interaction between visitors and the museum's physical–digital exhibition can reinforce the museum mission and drive new typologies of immersive experiences. Besides, the paper suggests improving the design and ergonomics of the technological devices (e.g., format, museum information, customisation and usability) to facilitate interaction and then create memorable immersive experiences that drive post-visit behaviours. By designing and implementing diverse technological interfaces, museum managers can change the traditional interaction modalities with visitors, providing new functionality of behavioural interactivity and enhancing the paradigm shift in the museum experiences. Indeed, traditional and 4.0 experiences express this change and, in turn, identify other unusual and immersive experiences as edutainment, reinforcing the museum identification as a multi-experiential context.

Furthermore, this study offers new scenarios of investigation on how the value of MR represents a business issue for museums, other organisations and IS developers. Measuring the positive (or negative) effects of museum immersive experiences and evaluating their impact on visitors' desire to reuse digital technologies can offer opportunities to introduce new digital technologies reshaping museums' missions and products. Museum managers and IS developers can capitalise on the visitors' intention to reuse immersive experiences and invest in several technologies (e.g., digital galleries connecting museums around the world and pre-experience virtual visits) to differentiate museum offers and targets.

Finally, the role and the effects of the multifaceted authenticity in immersive experiences require a more profound analysis, which challenges museum managers and practitioners. Measuring the perceived authenticity under conditions of immersive realities can support designing a museum as a sustainable combination of preserved heritage and user-driven innovation.

8. Limitations and future research

Although this paper draws research avenues and presents managerial implications, it also possesses some limitations, which suggest possible future research advances. The first limitation concerns the investigation of a cultural heritage museum in Italy in which the high value of the historical and cultural heritage exhibition influences the typologies of experiences.

In addition, various typologies of museums – science museums, industrial museums and more – will be analysed to compare diverse findings and design advances in investigating the relationships between functional dimensions, experiential dimensions and behavioural effects. The analysis of the only national Italian context represents the second limitation. Cross-country analysis, supported by cross-cultural national variables, can open new research scenarios in interpreting how cultural variables can influence the diverse visitors' profiles during MR use in the museum.

Considering the 13 hypotheses which were structured and accepted in this study, future research could reduce the constructs and hypotheses and integrate new metrics. Testing additional constructs consolidated in the literature (e.g., presence, involvement and acceptance), combined with new variables measuring sickness under conditions of immersive technologies, could challenge new interdisciplinary research.

The effectiveness of immersive technology in promoting post-experience behaviour remains a flourishing area of investigation that involves museum research and influences other tourism businesses in destinations. It requires advanced analysis methods, and therefore, future research can deepen the construct of behavioural effects, introducing other constructs and connecting them with new variables measuring constraints and obstacles in experiencing immersive technologies. It will adopt mixed methods that combine exploratory qualitative research − involving experts in various fields (e.g., museums, services, tourism and technology) to frame innovative constructs measuring behavioural effects – with quantitative research including surveys in different phases which measure both on-site experience and post-experience.

Furthermore, future research should test this conceptual framework in the post-COVID-19 era. The increasing impact of COVID-19 on the tourism industry is accelerating and amplifying the use of VR, AR and MR to enhance the value of the cultural heritage. New realities allow an immersive experience with visitors remaining safe at home, improving their sense of well-being. Future research should explore if the traditional immersive experience remains a consolidated form of the museum visit. Alternatively, researchers could study how new lifestyles, promoted by social distancing, can drive a shift towards 4.0 and 5.0 immersive experiences in which entertainment, socialisation and escape prevail and influence post-experience behaviours. This might raise questions as to how the increasing impact of COVID-19 on tourism can accelerate and amplify the use of MR in the cultural heritage, reimagining a museum visit in which visitors remain safe at home and live alternative immersive experiences to stimulate the planning of future behaviours.

Conceptualising and measuring the multifaceted authenticity in the immersive museum experiences domain is still in progress, requiring further academic investigation, including the application of the existing scale (quality commitment, heritage and sincerity) of the brand authenticity domain.

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