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Smart technologies in the museum environment. AR experiments on physical models at the Museum of Oriental Art in Turin

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Abstract

The concept of Smart Tourism has developed rapidly within the Smart Cities paradigm, which emerged at the beginning of the new millennium in various scientific fields. Museums, traditionally centres of cultural and technological dissemination and display, are becoming places to experiment with smart technologies (digital survey, AR, VR, digital fabrication, and AI) for analytical purposes and to enhance the visitor experience. This technological revolution affects the way museum visitors interact with cultural heritage. This process is part of the Fourth Industrial Revolution and is based on multiple technologies that blend physical and virtual environments. These tools have shown benefits for accessing, comparing, and understanding space-related information about artefacts and advantages in developing compelling forms of storytelling aimed at visitors.

Trying to give an overview of the technologies used, which have some relevance to the disciplinary field of representation, one can talk about digital acquisition techniques, Augmented Reality, Virtual Reality, digital fabrication, and artificial intelligence.

The models obtained with different digital acquisition techniques allow new ways of content fruition. Both virtual and physical outputs aim to increase the inclusiveness of collections, meeting the various needs of users related to age, physical, sensory, cognitive, cultural, and experiential factors.

The paper presents the outcomes of some experiments conducted in Museo d'Arte Orientale of Turin aimed to explore the continuum between real and virtual in the museum field through intelligent technologies. The experiments illustrate how to integrate AR technologies into the enjoyment of content, inside and outside the museum, with the support of real models.

Keywords: *Museum, Accessibility, Multisensory exhibition, Digital fabrication, AR.*

1. Introduction

The concept of Smart Tourism has rapidly evolved within the Smart Cities framework, which emerged in various scientific fields at the turn of the new millennium. Anything designated as "Smart" is characterised by the utilisation of Information and Communication Technologies (ICT) aimed at enhancing user experiences and providing analytical tools for institutions (Battino & Lampreu, 2019; S. Shen et al., 2020) identify numerous innovative technologies applied in tourism, including the Internet of Things, Cloud computing, Artificial Intelligence, mobile communication technologies, mobile devices and apps, Big Data, Virtual Reality, Augmented Reality, intelligent chat robots, wearable devices, and beacon networking. This network thrives on continuous interaction between the physical and digital realms.

Museums, traditionally hubs for cultural and technological dissemination, are now experimental grounds for smart technologies, improving analytical capabilities and enriching visitor experiences (Wang, 2021). A 2020 study by Mateusz Naramski on their use in Polish museums offers an international overview of these applications (2020). Examples include Near Field Communication (NFC), utilising intelligent object monitoring and preservation technologies, integrating audio guides with Augmented Reality, and analysing visitor profiles to address their needs and expectations.

The COVID-19 pandemic has accelerated the adoption of intelligent technology in tourism (Fong et al., 2020), marking a transition from traditional to smart tourism (Hassannia et al., 2019).

This technological revolution is reshaping how museum visitors interact with cultural heritage.

Universities and museums worldwide are digitising collections through techniques like 3D scanning, Computer Aided Design (CAD), and Virtual Reality (VR) (Comes, 2016). Notably, interactive and immersive experiences, mainly AR, VR, and other technologies, have been extensively studied in the Cultural Heritage domain over the past two decades (Bekele et al., 2018; Luigini, 2019), enhancing visitors' access to artefacts and storytelling.

Key technologies relevant to representation disciplines include digital acquisition techniques, Augmented Reality, Virtual Reality, digital fabrication, and artificial intelligence, all contributing to new ways of experiencing content. Virtual and physical outputs aim to increase collection inclusivity, addressing diverse user needs based on age, physical abilities, sensory perception, cognitive factors, cultural backgrounds, and experiential preferences.

VR technologies offer lifelike experiences and additional contextual content, albeit with associated costs and equipment requirements (Charr, 2024). Augmented Reality, often part of gamification processes (Rocha, 2020), provides intuitive spatial information by overlaying digital content onto the real world (Amin & Govilkar, 2015), transforming in-situ visits.

AR, like direct tactile experiences, fosters new interaction possibilities, including for individuals with sensory or cognitive disabilities, offering auditory, haptic, and olfactory experiences (Sheehy et al., 2019).

Modern museums emphasise physical or virtual object manipulation and multisensory experiences, engaging all senses. Examples include the Louvre Abu Dhabi or the Touch Gallery at the Louvre Paris, which showcases comprehensive exhibitions featuring digitally fabricated replicas and tactile stations.

Digital fabrication complements this by creating tactile replicas or models that deepen object understanding and engagement, embracing a "Design for All" perspective (Ronco, 2021).

Museums increasingly employ artificial intelligence to develop tools like robots, chatbots, and websites for data analysis related to visitors and collections (Styx, 2023). Object recognition operations, central to representation research, are employed by numerous museums based on colour, form, line direction, or spatial and light characteristics (e.g., Cooper Hewitt Smithsonian Design Museum, Dallas Art Museum, Barnes Foundation).

The combined use of AI, AR, VR, and digital fabrication represents a vital area of investigation, catering to a broad audience inclusively.

2. Aims and objectives

By examining surveying and digital fabrication technologies, along with research on multisensory pathways in museums and perceptual modalities beyond sight, this study seeks to achieve two main objectives:

- Develop a workflow encompassing digital acquisition by creating a digitally fabricated tactile model coupled with an augmented reality (AR) experience.
- Establish guidelines for an inclusive, multisensory, modular, and adaptable exhibition pathway that includes architectural and exhibition spaces and a curated selection of artworks.

The work proposes an inclusive approach to knowledge, catering to a broad audience, including non-experts. The 3D models serve as interactive spaces, encouraging the exploration of diverse scenes using user-friendly, affordable systems. Combining AR with direct haptic experiences opens up novel interaction possibilities, enhancing sensory engagement and knowledge dissemination (Sheehy et al., 2019).

Tactile media can be rendered interactive through Text-to-Speech synthesis (TTS) that enriches object augmentation, eliminating the need for physical transit between objects and associated captions. Audio feedback facilitates interactive tactile graphics, leveraging TTS to describe content and events (Thevin & Brock, 2018).

The presented case study is Museo d'Arte Orientale in Turin (MAO), a prominent and dynamic institution within the Italian landscape dedicated to presenting, appreciating, and disseminating Asian arts and cultures. Housed within Palazzo Mazzonis, a baroque building dating back to 1639 that underwent significant alterations in the 18th century, the museum is structured around a central core flanked by two wings enclosing an inner courtyard accessible from the street via a grand collonaded atrium. This atrium leads via a double staircase to the distinguished hall of honour on the first floor. These spaces have primarily retained their original structure, albeit with some modifications to their decorative elements.

In terms of its collections, the MAO currently boasts a repertoire of 2,500 artworks originating from diverse Asian countries spanning various historical periods, categorised into five main areas—South Asia, Southeast Asia, China, Japan, and the Himalayan Region—based on historical and geographical contexts (Bruno & Ricca, 2010).

MAO has consistently demonstrated an interest in leveraging digital technologies for heritage communication, mainly through online platforms (website, social media pages, YouTube channel, and Google Arts and Culture). However, physical visits to the museum's permanent collections currently incorporate limited multimedia elements, primarily audio guides, and need additional supports to ensure inclusive access, such as tactile models, dedicated audio descriptions, or LIS (Italian Sign Language) format.

3. Methods and procedure

This project targets various types of outcomes. The structured process is segmented into three stages, traversing the spectrum between reality and virtuality. The virtual phase involves digital survey, redrawing, digital modelling, and maquette development; the real one encompasses tactile reproduction, and the AR experience exemplifies the virtual-real one. As a result, this initiative operates across multiple perceptual visual, hyper-visual (AR), and haptic (Ronco, 2023).

The suggested workflow suits the container (exhibition spaces) and the museum's content (artworks). The initiative encompasses the architectural spaces and ten artworks (two for each geographic collection area) chosen based on specific criteria: ease of handling and inspection, ability to be illuminated, surface texture, clarity of details, opacity, and colour richness.

Photogrammetry was utilised for the artworks, while two metric surveys were done for the spaces. One was carried out by Professor Concepción López González (Universitat Politècnica de València) with a terrestrial laser scanner (TLS), and the other by Fabrizio Natta (Politecnico di Torino) with Structure from Motion technique.

The outputs of the digital surveys have been used for the virtual 3D modelling through Rhinoceros® software at the base of real models, conceived from the perspective of tactile fruition and experience, easy to handle, and perceivable at the same time.

Finally, in this experimentation, we opted to evaluate marker-less anchor AR due to its capability for direct interaction with real-world models. Unlike MR and VR, AR generally offers a lower level of interaction.

In particular, this paper focuses on the atrium of Palazzo Mazzonis and artwork from the Chinese collection.

3.1. From digital survey to digitally fabricated models

3.1.1. Architectural spaces: the container

The spaces digitally surveyed by the research group led by Prof. R. Spallone and M. Vitali belong to the ceremonial route and include the atrium (Figure 1), the staircase, and the hall of honour on the first floor of Palazzo Mazzonis, home of the MAO.

The modelling process of the space, based on the point cloud acquired through the TLS technique, starts with identifying the distinctive horizontal and vertical sections. The model has been done with Rhinoceros®, drawing on point cloud sections and obtaining closed solid poly-surfaces (Figure 2). This ensures an optimal result in the digital fabrication phase.

The maquette of a portion of the atrium, designed at a scale of 1:50, is constituted of four parts: the base, made with a laser-cut printer (Trotec speedy 400) on MDF panel; the wall; the entablature and the column 3D printed with Fused Deposition Modelling (FDM) technique in PLA (Ultimaker S5). MODLab Arch of the Department of Architecture and Design supplies both machines.

The printed parts are linked with magnets to facilitate the assembly from an inclusive perspective (Figure 3).

Figure 1. Palazzo Mazzonis' Atrium. Source: Google Arts and Culture.

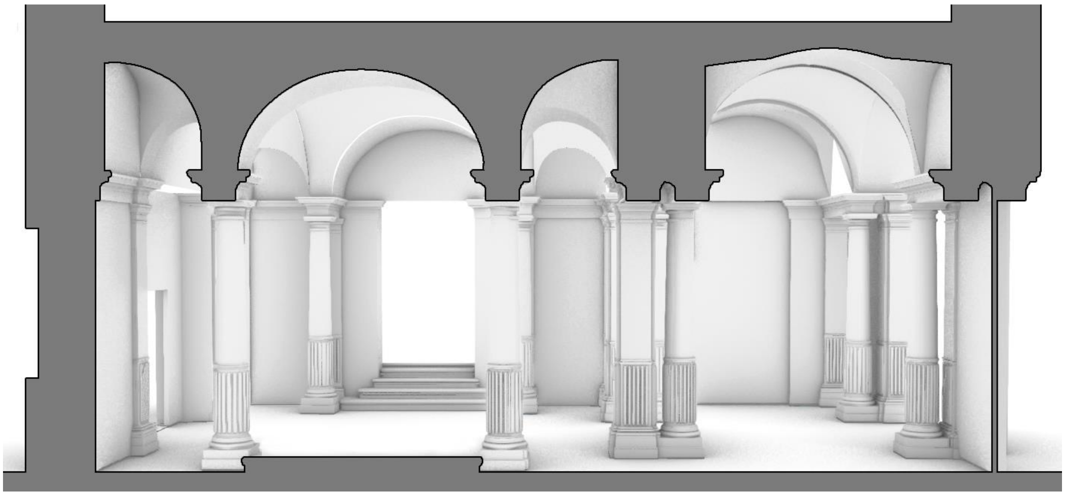

Figure 2. Palazzo Mazzonis' Atrium 3D model's longitudinal section. Modelling: Awada, A.

Figure 3. Maquette of a portion of Palazzo Mazzonis' Atrium. Model engineering: Ronco, F.

3.1.2. Artworks: the content

Conversely, the work on artworks starts from a photogrammetric digital survey. Here, the author presents a Chinese tomb statue of an actor (Shaanxi area, VII century AD) belonging to a group of four travelling foreign actors (Figure 4). The selected one, the shortest of the four, addresses a hypothetical spectator directly, spreading his arms wide in a theatrical gesture that the other three follow in a mimetic fashion. The tunics with billowing sleeves constituted the typical attire of the show, and the vast, bipartite headdresses belted with ribbons (futou). According to some reconstructions, these figures belong to the people of the Sogdians, an ancient kingdom in Central Asia of which most information has been lost.

The replica in PLA has been realised at a scale of 1:1 with the FDM technique (Figure 5), following principles to allow the reader/user an easy vision/perception of the whole figure based on the simultaneous use of two hands (Levi & Rolli, 1994). The 3D printer (Bambu PS1) of the MODLab Arch laboratory of the Department of Architecture and Design has been used.

Figure 4. Museo d’Arte Orientale, Chinese collection: travelling foreign actors (Shaanxi, VII century AD). Photogrammetric survey and processing: Ronco, F.

Figure 5. Foreign actor 3D printed replica. Print: Ronco, F.

3.2. The AR Experience Design

AR experiences have been developed on the presented real models with Unity® and Vuforia SDK.

Vuforia™ Engine, leveraging Model Target technology, enables recognition and tracking of real-world objects using standard mobile devices. Initially, the virtual models must be transformed into recognisable features for the software. Vuforia™ offers the Model Target Generator tool, which converts the objects’ polygonal mesh into a three-dimensional model suitable for integration into Unity® as a target.

In both cases (atrium and actor), the Advanced Model Target allows a 360° recognition of the model. The Model Target Generator software requires you to confirm the orientation of the .obj file since the system of Cartesian axes used in Rhinoceros® is different from that used in Vuforia™ and Unity® and to express the unit of measurements. Finally, an advanced Guide View has been created, as the developer wants it to frame the object at 360° on a plane. In the end, the Model Target is trained and exported to a .unitypackage file to be imported into the project on Unity®.

After the object recognition, all assets regarding the 3D model (different architectural parts and the textured model of the actor) and the Canvas (children of the Model Target) appear.

Inside Canvas are all the user interface elements, such as lettering and buttons. There is also an Event System associated with the Canvas, which does not appear in the scene but is responsible for managing the interactions of the Canvas and its elements.

In the "container" application, five UI buttons trigger the various architectural parts of the maquette to teach the user their correct nomenclature. On the other side, the application on the actor includes only one button that activates written and audio descriptions (Figure 6).

The layout of the controls on the right of the screen provides for using the screen in a vertical position. For each button action associated with it, the OnClick window indicates which Game-Object to act on; for all buttons, the Set Active command allows the actuation or deactivation of the referenced object (Figure 7).

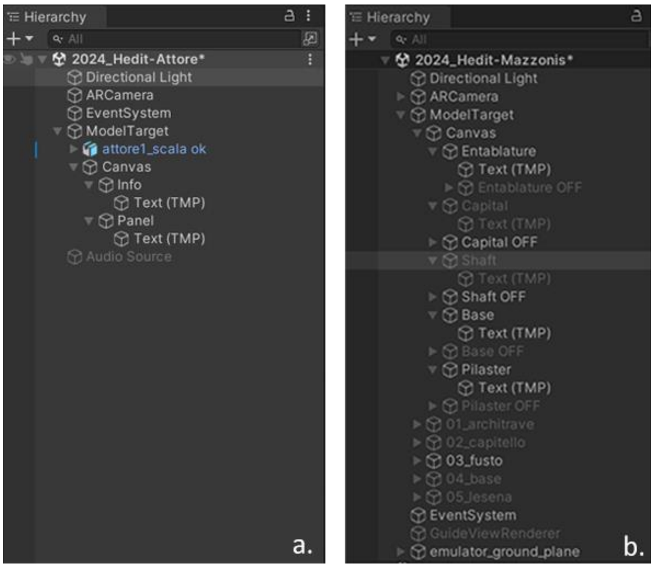

Figure 6. Unity® *project hierarchy: a) Actor's app; b) Atrium app.*

Figure 7. Palazzo Mazzonis Atrim app: a screenshot of the AR experience.

In the actor app, the audio content was created using MURF.AI Studio, a text-to-speech software featuring a diverse selection of over 120 natural-sounding male and female AI voices across 20 languages. This range of options enables easy implementation and customisation of the application based on specific requirements.

Subsequently, the TMP content and audio were integrated into the model target to display after framing the model and clicking the *info* button. The descriptive texts and audio relating to the statue enhance the haptic experience, improving the accessibility of the content (Figure 8).

Figure 8. Actor’s app: a screenshot of the AR experience**.**

4. Results

These activities are part of broader research conducted within the scientific collaboration agreement between Politecnico di Torino and Fondazione Torino Musei. Specifically, they involve the Department of Architecture and Design and the MODLab Arch and MODLab Design Research and Teaching Laboratories at Politecnico di Torino under the supervision of MAO’s team.

In this framework, the presented research endeavours to develop a workflow model for managing the digitisation of artworks and exhibition spaces, culminating in creating tactile replicas and AR applications. A notable research gap exists in workflows and methodologies, leaving critical questions unanswered regarding scale, material selection, and public presentation methods (Wilson et al., 2017).

From social and economic standpoints, tactile exploration of artefacts and AR experiences undoubtedly enriches visitor understanding and engagement. Furthermore, integrating tactile experiences with audio descriptions adds significant value, enhancing the museum experience from an educational and inclusive "Design for All" perspective.

The most important result of the broader research is the funding (European Union under National Recovery and Resilience Plan - PNRR M1C3-3) of a project to eliminate physical and cognitive barriers in museums and public cultural places. The project written with the MAO’s team seeks to enhance knowledge accessibility through the continuum between real and virtual, or in other terms, physical and digital realms.

This encourages us to pursue the goal of creating a model, establishing a shared language to minimise errors in museum institutions' accessibility assessments, and streamlining users' multisensory experiences, making them more intuitive and less reliant on introductions and explanations.

For this reason, a multidisciplinary team has been assembled for the overall project implementation, incorporating expertise in multisensory museum communication, tactile experiences, digital art, and multimedia, combining curatorial knowledge with that of heritage representation (Ronco, 2022; Spallone et al., 2022; 2023).

5. Conclusions

Emerging technologies facilitate the preservation and enrichment of cultural heritage and provide new avenues for interpretation and more impactful communication. In particular, the partnership with MAO provides opportunities to explore diverse representation languages to enhance museum heritage accessibility from a *Design for All* perspective.

In particular, digital fabrication and AR straddle the boundary between the real and virtual realms, amplifying the levels of understanding and interpretation of museum content or its container. The physical model itself results from a reworking of previously gathered data, representing the culmination of a project. Augmenting it enhances effectiveness, promotes increased interactivity, and adds a playful dimension. This engagement leads users to deeper involvement, improved recollection of the experience, and enhanced learning.

Employing VR, AR, tactile models, and other cross-media techniques deepens the connection between the museum and its visitors. Leveraging the continuum between real and virtual, physical and digital realms, it offers a workflow adaptable for diverse operators and accessible to various audiences. This formula holds promise for scalability across different museum contexts.

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