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Multisensory Museums, Hybrid Realities, Narration and Technological Innovation: A Discussion Around New Perspectives in Experience Design and Sense of Authenticity

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Abstract: This paper focuses on the topic of multisensory museums, conceived as extended or hybrid realities where real and digital coexist to offer cognitive and emotional engaging experiences to the public and increase the sense of authenticity. Multisensory communication can increase accessibility, as it conveys the content through multiple perceptual channels, and it can solicit more inclusive, participatory, and creative audience engagement through the stimulation of emotions. A methodological approach to digitisation, communication strategies, interaction, creative storytelling, immersive technologies and accessibility issues are discussed in depth, in relation to novel museological practices. Machine learning and generative AI are opening new scenarios in management practices and decision-making processes, in data analyses and in natural language processing, and in the creation of customized content addressed to the audiences. A short overview about how these algorithms evolve and work is presented, considering challenges, threats, expectations and ethical implications they pose. Another topic is the sense of authenticity. How is it changing in today users? How phygital realities, storytelling and user experience design in museums can influence it? The paper will discuss these issues, presenting also some case studies, which have cultural, social, philosophical, and ethical implications, at a time when museums are redesigning their role in a society undergoing profound transformation.

Keywords: extended reality in cultural heritage; interdisciplinary approach; multisensory experience in museums; interaction; accessibility; embodiment; authenticity; narration; artificial intelligence; ethics

1. Introduction

1.1. The Museum Between Map and Territory

Territories and 'meta-territories' of the cultural objects are variuos: the place in which, or for which, they were created, or a new space, different from the original one, in which they are displayed to the public, as a museum. A non-place, the latter, an abstract, metaphysical space in which the logical connections among objects are divorced from their original reasons for being. On the other hand, the museum is also a new territory, a living space, crossed by people that, hopefully, want not only to look at objects but also to experience them, understand them and get excited by entering their stories. Multiple contexts therefore intertwine. The past life of the objects and their present life establish a relationship with the experience of those approaching them [1].

Therefore, the process of contextualization of the cultural object and attribution of meaning is diachronic, evolving through different cycles of interaction, through variations and redundancies, and differ from era to era, from person to person.

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The virtual dropped into the real museum should foster a less hurried and consumerist, more profound comprehension of the cultural heritage, but also a creative approach, capable of soliciting the individual on multiple perceptual, cognitive and emotional levels.

So, thanks to multimedia and phygital realities, museums can become active workshops of cultural experiences that build bridges between lives/cultures of the past and our time.

1.2. Structure of the Paper

This paper focuses on the topic of multisensory museums and the design of effective hybrid realities applied to cultural heritage, that is cultural experiences were real and digital are combined and integrated, aiming at representing and transmitting cultural heritage to the public in an innovative and engaging way, considering both tangible and intangible values. The impact of multisensory communication in museums, empowered by technological innovation, will also be considered in relation to the sense of authenticity of the cultural message perceived by the public entering in contact with such "extended" museum contents. Which are the criteria to design a deep, useful and rich cultural experience? How can we stimulate in the audience involvement, understanding, memorization, imagination and creative elaboration?

Considerations expressed in the article come from the author's academic background in preservation and valorisation of cultural heritage, art-history and museology [2] and from her 25 years' research activity and experience, in the field of digital innovation in cultural venues and virtual museums. They are corroborated by the results of several surveys carried out on thousands of visitors approaching digital contents in Italian and European Museums.

Section 1, the introduction, presents the main concepts and topics, the purposes and the privileged target of this contribution. It introduces the concept of extended reality and phygital experience and the reasons for their use in museums and cultural venues. The state of the art of multisensory experiences in museums is discussed in relation to ethical issues, as accessibility, richness and reliability of contents, sense of authenticity, connection with the territory, inclusivity, and considering the new frontiers disclosed by artificial intelligence (AI), NFT, metaverse and by the consequent new value chains. Then the user-centered approach in communication is introduced, where perception, action, motivation, emotion and cognition are addressed at creating involving and memorable experiences, according to logics other than fast cultural consumerism. **Section 2**, Material and Methods, presents the basic principles of multisensory museums: narration, interaction, progressive immersion and understanding of contents, mixed reality, tactile interfaces, media combination and hybridisation, individual and social dimensions, sense of wonder, soundscape, embodiment. An important discussion develops around the sense of authenticity, which is connected to a multiplicity of rational, emotional, individual, and social factors. Essential preconditions are the good quality of digitisation and the reliability of virtual reconstructions of lost or fragmented contexts, whose criteria are shortly summarized by the author. Besides, the user-centered approach is closely connected to target audience profiling, where traditional methods are complemented and exponentially enhanced by artificial intelligence which is revolutionising the field of cultural marketing. The Use of AI in the Cultural Heritage and in Museums Sector are discussed, considering a wide range of activities and applications, including a reflection on opportunities, threats and ethical issues. **Section 3**, Results, presents some case studies in whose development the author was actively involved. They have been chosen to concretely exemplify principles and methods discussed in the previous section. Purposes, target, processes and technologies applied to each of them are shortly presented in their most meaningful aspects. **Section 4** discusses, in the light of the previous sections, how the museum should be considered as a dynamic place of evolving narration, where the visitor can live perceptual experiences that are unique and not equally repeatable outside the museum, beyond the opportunities offered by smartphone which people commonly use in their daily life to reach every kind of contents. Emphasis is placed on the design of the museum experience which must be rooted on effective integration of real collections, digital content and exhibition layout: real and digital should dialogue, to polarise the visitor's attention and emotion on the place in which he/she

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is currently immersed. **Section 5**, the conclusion, summaries the main content and the emerging values of this work, opening perspectives on future desirable developments and directions.

1.3. Museum, Virtual Heritage and Extended Reality

Today in most museums we can approach the objects on display almost exclusively with the aid of sight: we can look at the artifacts but we cannot touch them, not listen to the voices or sounds they hold back (think about textual or musical contents of manuscripts, or epigraphs, that remain totally unexpressed to the public, as in most cases their language or writing are difficult to decode today), we cannot perceive their smells, nor we can be aware of the artisanal processes that produced them. In most cases our approach to cultural object is still formal, tassonomic, abstract.

Nowadays, thanks to social media, the museum promotes itself as a potential centre of open cultural production, dialoguing with its audience. This phenomenon must be managed according to an open but authorial strategy, in which the museum, as a cultural and educational institution, welcomes instances and 'stories' proposed by its public but manages and directs them while maintaining a guiding role, envisioning and evolving new perspectives, including but not chasing the demands of its users.

The digital life of the museum cannot be exclusively linked to social media. The layered paradigms of the virtual museum [3] can help in implementing a new digital curatorship, based on high audio-visual quality of content, aesthetic enjoyment, the creation of a continuum between the experience of the real and the virtual contents, structured storytelling, virtual and mixed reality, sensory immersion and a sense of presence within stories and environments. Multisensory solicitation can evoke, around objects or lost contexts of life, the sensorial, perceptive and symbolic dimension, which would otherwise be completely unexpressed. Through the virtual dimension lost relations between objects, ages, stories, contexts can be restored, represented and experienced. What is mostly important, in the virtual dimension, is not the objective description, the digital replica of the real artifact, but the interaction processes that can be activated, that are open, personal, and diversified [4]. Thanks to the digital "extension", objects and places can be usefully perceived and understood in their:

- shape, eventually digitally restored;
- context, through virtual reconstructions or mixed reality;
- technical processes, symbolic values and social attribution of meanings, through storytelling.

A virtual heritage network is therefore a multidisciplinary and multidimensional network connecting objects, places, authors, contents, users, real worlds and virtual dimensions. Extended reality is a "continuum" where real and virtual co-exist and are combined, enhance and validate reciprocally. Multisensory communication is instrumental in increasing the accessibility to museum content as it conveys contents through multiple perceptual channels, and it can solicit inclusive, participatory, and creative audience engagement through the stimulation of ideas and emotions. Making the space alive allows to break down the isolation of the objects from the public, increase the sense of fear and wonder [5], astonishment and empathy and ultimately encourage exchange and dialogue between people [6]. Audio-visual, tactile, even olfactory or gustatory narration, if guided by criteria of truthfulness and historical plausibility, allow the public to feel embodied in the experience and delve deeper into a interconnection of meanings, tangible materials and symbolic values.

Storytelling is another key element in the processes of engagement and immersion in the cognitive experience. It should shape the museum space and the way of organizing and approaching the collections, fostering both intimate reflection and interactive collaborative experiences, through a variation of audiovisual languages, interaction levels, and technologies chosen to convey stories [2].

As a public place of education and culture, the museum is inclined to favour collective communication, social sharing and exchange. The various forms of content representation, languages and technologies are usually chosen to engage groups of people. But on the other side museum should foster also intimate reflection and self-awareness. It is increasingly common to find, in the

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museum, a space with few seats where users can enjoy an individual experience of immersive virtual reality (VR) wearing head mounted displays, but the quality and the integration of this kind of experience into the museum pathways is still not fully convincing. If museums will be able to usefully take advantage of the challenges offered by creative languages and innovative technologies, favoring quality instead of quantity, they can become privileged guides and interprets of social demands, especially of the young generations. Therefore, privileged recipients of this contribution are museum and cultural venues curators, involved in preserving, enhancing, and protecting cultural heritage, as well as university and school students, cultural and creative industries, and in general all those people aiming at creating culturally useful, accessible, participatory experiences that generate a sense of well-being in the individual and the community.

1.4. State of the Art

The visit to the museum must offer a unique experience based on the richness and depth of the contents: collections, high quality audio-visual narration, interaction, multi-sensory immersion, embodiment, emotion, are essential elements in the creation of an experience and are the paradigms of virtual museums. But where are we now?

In Prague, on 24 August 2022, the Extraordinary General Assembly of ICOM has approved the new museum definition with 92,41%: "*A museum is a not-for-profit, permanent institution in the service of society that researches, collects, conserves, interprets and exhibits tangible and intangible heritage. Open to the public, accessible and inclusive, museums foster diversity and sustainability. They operate and communicate ethically, professionally and with the participation of communities, offering varied experiences for education, enjoyment, reflection and knowledge sharing.*" [7]. This is a more up-to-date definition of "museum"- coherent with current times and the ever-changing dynamics of the world of Culture, in comparison with the previous definition dating back to 2007: "*A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment*".

In the new definition, ethical concepts such as accessibility, inclusiveness, diversity, sustainability and community participation are underlined. The part in which the vision and the intellectual mission of museums are explained remains unchanged, understood as places of conservation, research, exhibition of artifacts.

Besides, a resolution by the 31th General Assembly of ICOM in 3-9 July 2016 in Milan, disciplined the responsibility of museums towards landscape [8]: "*Museums are part of the landscape. They collect tangible and intangible testimonials linked to the environment. The collections forming part of their heritage cannot be explained without the landscape. Museums have a particular responsibility towards the landscape that surrounds them, urban or rural[…] The concept of Cultural Landscape incorporates not only the physical size of a territory, but also a wide range of intangible factors - from language to lifestyle; from religious belief to the different forms of social life; from technology to ways of life and production, as well as to power relations and exchanges between generations. […] Such concept encompasses soundscapes, olfactory, sensory and mental landscapes, and also the landscapes of memory and of conflict, often incorporated in places, objects, documents and images, endlessly expanding opportunities for museums to take action on cultural landscapes*".

It is clear the interdisciplinary approach that museums need to adopt in their curatorial practices and multidimensional interconnection, where the link with the digital is an essential part to create global and local dimensions, new real and virtual communities.

Currently, museums and cultural venues are embracing the digital challenge with increasing confidence, but real and virtual are mostly juxtaposed in the cultural offer, separately, they do not really interact with collections. In many cases digital content offer an accessory experience, introducing the main topic of the exhibition at the beginning of the visit path or they offer additional contents like for instance interviews to the experts or documentation of contemporary artists, in the form of non-interactive movie (most of time with subtitles and without audio). Multimedia rarely is

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used to present simulations, tell stories and attribute meanings to the exhibited artifacts along the path of visit. The connection with the territory and the cultural landscape is still very poor. Similarly, they are rarely used to encourage interaction or stimulate creativity, astonishment in the public, or a deep contact with us ourselves, or with the artist's concept (a part some exhibitions of contemporary art). Dialogue and interaction among users take place on social media but not in the museum space. Increasingly, museums adopt supports and arrangements to make cultural content accessible to people with physical and perceptive impairments, but these are still partial interventions.

Since 2005 the importance of the relation between heritage and human rights and democracy**,** as a condition for the social, cultural and economic growth of the communities, was empathized by the Convention on Value of Cultural Heritage for Society (Faro Convention) [9]. In the following years many initiatives followed, in line with the Faro Convention, at international European and national levels, with an increasing attention to **accessibilit**y. In 2019 the International Council of Museums (ICOM) presented at the 25th General Conference in Kyoto, in accordance with the Italian Ministry of Culture, the guidelines regarding accessibility [10], inclusion and usability in museums)[11,12], encouraging the opportunity of creating an International Committee on Accessibility (motor, sensory and cognitive disabilities, social fragility, etc.); therefore many governments are recently supporting this issue. In December 2019 a new version of the European guideline "Accessibility requirements for Information and Communication Technologies (ICT) products and services"(EN 301549) [13] was published, to specify functional accessibility requirements applicable to ICT products and services, to be used in public procurement in Europe. In line with these principles, in 2024 Italian National Research Council, in collaboration with the Italian Ministry of Culture and the Italian National Radio-Television (RAI), published the "Design manual for accessibility and expanded enjoyment of cultural heritage. From the functioning of the person to the functioning of cultural places" [14]. More than thirty experts representing diverse backgrounds contributed to this work, which offers targeted guidance for the functional design of cultural venues, practical cases, and with a reasoned legal summary. The manual presents a cross-cutting design for all heritage places, which include libraries, archives, museums, monuments, and archaeological areas. The focus is on the removal of architectural, cultural, sense-perceptual and cognitive barriers in cultural places, and on the functioning of cultural places rather than on the mere analysis of the characteristics of the users attending such sites. In this context multisensory and multichannel approach in communication is recommended as essential strategy, in relation to the Universal Design principles [15].

In museums, in particular, there is still a reluctance to combine real and virtual contents in the same experiential "frame," probably the worry is that the contribution of the virtual might shatter the absolute meaning of the object on display, its authenticity, assaulting it with ephemeral values.

In the last years the concept of "authenticity", as perceived in museums, has been investigated by some projects and articles [16,17]. Among these initiatives the PERCEIVE European project (Perceptive Enhanced Realities of Coloured Collections through AI and Virtual Experiences [18] has studied and detailed the concept of authenticity of the experience, rather than of the authenticity of the artifact itself, with the goal to improve the design of digital applications in the field of cultural heritage. It has been evidenced as authenticity encompasses various dimensions beyond mere realism: the "Self", the "Others" and the "World" [19].

According to [20,21,22], perception of authenticity arises when extraneous and impersonal subjects transform into something personal, intimate, touching our sphere of emotions, memories, or beliefs, and therefore involve us. In this sense authenticity is related to "identity" and genuine self-perception, at cognitive, emotional, and sensory levels. According to [23] authenticity emerges and evolves alongside the person, growing in depth along the time. Therefore, an authentic experience is perceived as deeply personal and unique to everyone, changing over time. Vannini and Franzese in 2009 [20] discuss how the "self" is intrinsically connected to the "others" by mean of explicit or implicit communication, external or internal, in presence or in remote, synchronous or asynchronous, what matters is the feeling to be part of a common thinking. Sharing the same system of symbolic

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values, or social practices, enhances the sense of belonging and therefore the sense of truthiness and authenticity.

The "world" is the external environment, the context in which the "self" is included, in this case the museum, or the cyberspace, or an extended reality made of a combination of real and digital entities. The perception of authenticity in this case is produced by the accessibility, the credibility, the realism of contents and their validation. Validation is often taken for granted and implicit when people trust the notoriety and scientific credibility of the author of the contents, or of the cultural institution that presents them, even in the absence of tangible and reasoned evidence of their origin. But validation can, and should, be also explicit, especially in the case of virtual objects and digitally reconstructed environments, as largely discussed in literature, especially in relation to virtual archaeology, virtual restoration and virtual reconstruction in cultural heritage [17].

Multimedia productions for cultural places have greatly evolved in the last ten to fifteen years in terms of aesthetics, resolution and accuracy of graphical representations, multisensory solicitation and sensors integration. This has been made possible by the progress of methodological research and technology that have implemented hardware and software solutions that are increasingly integrated, powerful and accessible. And there is no doubt that museum managers and curators have shown a gradual openness to the potentialities of digital, partly overcoming initial resistance. Laboratories and creative industries working in these areas have therefore increased in number exponentially, but unfortunately the economic models of sustainability are still highly deficient, especially in the medium and long term. Strategies and investments in maintenance, reuse, updating of content and modernization of technologies are lacking in most part of museums.

For this reason, museums are often prudent in incorporating permanently digital technologies into their exhibitions and educational programs. Most of the initiatives are temporary and their sustainability is guaranteed in the short term. Museums often join partnerships for experimental projects led by ICT institutions or industries, mostly focused on technological aims.

In the last years new frontiers in the domain of digital metaphors, services or virtual experiences have opened to the wide public, as marketing automation, artificial intelligence (AI), metaverse, NFT, Block Chain, which further condition the perception of authenticity, generating new value chain. For instance the Artemisia project, carried out in 2022-2023 by the Italian National Research Council; Digilab - Sapienza University of Rome, and the company iComfort, and financed by Lazio Region in Italy, [24], had the purpose to analyse the experience of visiting a museum by means of motion sensors and AI algorithms to understand the dynamics of users behaviour in relation to cultural content and architectural, organisational and didactic elements. It was a pilot study carried out in two rooms of the Museum of Rome in Palazzo Braschi, (Rome, Italy), recently renewed. Visitors' movements, head orientation, gender, were captured in real time, by motion sensors, in a totally anonymous form. Data were processed by AI algorithms to extract paths, and the idea was to address results to cultural marketing strategies. In fact, the final aim of the project was to study the impact of the visit with respect to cognitive learning, customer satisfaction and accessibility, to provide a grid of indices for the improvement of future museum visits and an advanced cultural profiling model. The project remains in the research domain, given its experimental nature, with no application in the museum at present.

In 2018 the British Museum, the first national public museum born in the world in 1753, announced to enter the Metaverse via The Sandbox [25], a virtual 3D world with a its own economy based on Ethereum [26], a decentralized global software platform powered by blockchain technology. In the Sandbox the British Museum creates and offers Non-Fungible Token [27] objects that reflect the breadth and depth of the museum's collections and that can be acquired and collected by investors through cryptocurrency. The British Museum announced also to create its own immersive space within the online game world, to explore "new and innovative ways of sharing its collection and reaching new audiences" [28].

Besides, the emergence of new social media and paradigms enhancing cultural interactions among people induce the creation of specific social platforms for Cultural Heritage that encourage

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an active participation of many stakeholders. There is an increasing request of digital frameworks open to the communities for the accessibility, study, participatory and sustainable management of cultural resources and assets.

Therefore, the user experience design in a museum, as well as the study of museum visitors, are fundamental to understand how the museum can affect people's life and to let people feel involved, intimately and collectively, through a plurality of channels, in order to nurture a perception of authenticity. Personal expectations, intimate reactions, group identity, meaning making processes, memories enter in the experience, extending in space and time, beyond the on-site visit of the museum [29].

We could say that today the main challenge to be faced is to create a closer synergy and interconnection between four 'actors': the actual collections, the digital collections, the narrative and the public interactions, including different audience profiles, to create new scenarios of cultural experience that can last and evolve over time.

1.5. Key Factors of Multisensory Museums

An artwork is an artifact created by man, using any material, endowed with aesthetic characteristics, and imitating the natural or the spiritual reality. Every cultural artifact consists of a combination of materials, colors and shapes (aesthetic consistency) and in a convergence of expressive values, functions, and meanings (historical values) [30,31]. Art generates beauty and can arouse emotions, sensations and feelings, pervading our souls, bringing a feeling of harmony and happiness, shared by many people. However, there are many artistic languages and paradigms, and there is not a unique code of interpretation. Each artwork reflects the artist's opinions in the social, moral, cultural, ethical or religious context of his historical period, that today can be lost or difficult to understand. The reconstruction of sensory and symbolic dimensions that are "beyond" the object's appearance can take the visitor into the middle of a lively and powerful experience. How can this be done? Undoubtedly, multimedia technologies are the best means to convey contents related to cultural heritage, especially audio-visual, because they solicit a similar process of perception, elaboration and learning. Mixed and virtual environments allow the users to learn from experience, joining sensory-motor and interpretative faculties, perceiving, acting, even in contexts that are no longer (or not yet) materially accessible today. The alternation and the coexistence between real and virtual contents produces a cognitive anacyclosis; redundancies and differences that reinforce learning [32]. Virtual contexts can be variously assembled, dismantled and mounted again, to understand their deeper relations; they can be desynchronized, becoming scenarios of different simulations.

The user centered approach makes the concept of "experience", and therefore the user experience design, one of the main issues to be pursued in museums, together with content curation. Marc Hassenzahl [33,34] describes the user experience as a merger of perception, action, motivation and cognition, assuming close connection between actions, thoughts and emotions. In fact, he defines the experience as "an episode, a chunk of time that one went through [...] sights and sounds, feelings and thoughts, motives and actions [...] closely knitted together, stored in memory, labelled, relived and communicated to others. An experience is a story, emerging from the dialogue of a person with her or his world through action". An experience is thus subjective, holistic, situated, dynamic, and worthwhile. It follows that contents that should be experienced must be accessible and usable, useful and original, credible and desirable, they must satisfy a need and move emotions.

Several neuroscience studies published in recent decades [35] suggest that dreams are a form of continuous stimulation of long-term memory, throughout the course of life. A recent study of the New York University, led by the Hungarian neuroscientist György Buzsáki [36], found that the conversion of everyday experiences into permanent memories occurs for a significant part when we sleep. Sleep therefore acts on the brain as a kind of memory wipe, useful in determining which thoughts to retain as long-term memories and which to discard. The brain reacts to certain experiences with ripples in the brain waves that are then reactivated during breaks or sleep, fixing

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them in memory. This research further explains the importance of the stimulation of multisensory dimension and emotions. The dream is in fact a psychic phenomenon linked to sleep and characterised by the perception of images and sounds recognised as apparently real by the dreaming subject. It is a kind of nocturnal thinking in which the utilitarian and rational pragmatism of waking life is suspended [37,38].

Human beings open their mind to the world through intuitive experience; sensing and emotions are fundamental in the life experience and in the self-identification process, they are the engine of knowledge and development of the individuals [39]. Every important moment in our lives, fixed in our memory, has been marked by emotions. "Sensing" a cultural context means also the capacity to enter in contact with those elements that let us "recognize" something and move our emotions. W. Shakespeare himself said: "We are made of the same substance as dreams, and in the space and time of a dream is gathered our short life" (W. Shakespeare, The Tempest, Act IV, Scene I, 1623), [40]. When we are embodied in a mixed reality or a virtual environment, engaged in audiovisual storytelling, maybe adopting gamification metaphors, dealing with spaces, ages and stories distant from our everyday life, we live an imaginative status.

But which are the **key elements** to be promoted in a multisensory museum to create a credible and deep experience? According to the author's experience, these key elements can be summarised as follows.

2. Materials and Methods

2.1. Narration

Usually museum curators prefer to be "neutral" regarding the artifacts, and they avoid telling stories or suggesting the visitors anything else beyond the pure evidence.

In the field of Cultural Heritage, visualization usually aims at analyzing what is still existing and observable. Unfortunately, avoiding interpretations of lacking context is not a neutral choice: if a visitor is left alone, without interpretation and "reconstruction", even if hypothetical, he/she will deduce even false and erroneous significance.

Learning does not arise simply from our reasoning, but also through curiosity, engagement, interest and attention; in one word, through motivation. In this process emotions play a crucial role, stimulating a feeling of self-identification, appropriation and elaboration of the meaning. Indeed, many surveys on user experience in museums [41,42], especially referred to the use of interactive digital applications characterized by technological innovation, have evidenced the crucial role of narration in this process. Narration, in fact, is more powerful than pure description. When using narration, evocation or even dramatization, objects become the occasional points where history "coagulates", creating an expectation in the visitors. Narration emphasises relationships, individual perspectives, variations, liveliness, empathy, and emotions connecting elements within the story, even in unpredictable ways and it draws up a specific space-time dimension [43,44]. Storytelling can stimulate the ability to reflect and bring out new thoughts, e.g., through reference to personal, family or popular facts, it can activate unexpected stimuli, provocations, or playful dynamics.

In a multisensory museum narration is not limited to a written or an oral text. It is referred to an expressive unity where many factors converge: oral performance/recitation, layout, visual mood, soundscape, camera movements, lighting, rhythms, smell and taste (although the latter two senses are not yet highly represented in cultural venues and in digital media in general). It is evident how important languages are in generating emotion, involvement and well-being.

In the creation of a narrative, certain and circumstantial contents regarding the artifact will be combined with plausible and probable ones, pertinent to its cultural context. Usually, the story construction is a long and collective process carried out by curators and creatives, which continues to be improved and reshaped until the final production: once the historical or archaeological information has been acquired, a process of synthesis begins, aimed at distilling the essence. Some

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messages are made explicit, others implicit or subliminal [45]. Through storytelling museums can propose a "visual drama" beyond what we can see, becoming scenarios of different simulations [46].

2.2. Interaction

If the objective is to convey educational, scientifically correct and plausible content, while at the same time arousing a strong conceptual and emotional involvement in visitors, interaction also assumes a role of great importance in making the user feel decisive in the development of the experience and in the construction of the story. As early as the late 1960s, the American pedagogue Edgar Dale demonstrated that content acquired through interactive experiences settles in our minds to a much greater extent than content of which we are passive recipients [47].

Interactions in a museum are multiple: between the user and the space, between people, between the user and the collections, between the user and technological devices, between the user and the digital content. This complex frame translates into many behaviours and cognitive dimensions that determine actions and emotions. It is therefore necessary to find a good balance between free interaction and guided experience, to optimise the effectiveness of cultural transmission and both personal and collective stimuli.

Interaction can be active or passive. It is active when it is explicit, e.g., verbal with other users, or when technological devices must be used to activate content or events, or when people act together and co-create a common experience within a real or digital scenario. On the other hand, interaction is passive when one's mind and feelings are stimulated by a suggestive story or situation, the vision of a beautiful picture or the listening to an evocative sound, which trigger associations of ideas, cognitive excitement. This applies to each of our five senses. Clearly, all perceptions and interactions are open to subjective interpretation and therefore the experience differs from person to person. To make the perceptual and interactive experience positive for most people, it is necessary to make use of usability principles recognised as shared by psychologists and neuroscientists [48] and good practices in user experience design [49]. Therefore, interaction implies a good visual design and physical affordances. Thus, the concept of "affordance" is fundamental because it leads us towards the attribution of functionalities to real and digital artefacts. The psychologist Gibson [50,51] defined "affordances" all the "action possibilities" latent in the environment, objectively measurable and independent from the individual's ability to recognize them, but always in relation to agents and therefore dependent on their capabilities. According to Gibson what we perceive when we look at objects are mainly their affordances, not their dimensions and properties because the physical aspect of objects allows us to understand the principles of their functionalities. Consequently, the concept of affordance is related to the concepts of perception, usability, design, interface, interaction, shape, colour, interpretation, embodiment.

In the case of digital content and applications, active interaction should not be unnecessary and strenuous for users; instead, it should be calibrated for various types of users, confident or not with interactive technologies and interfaces. To achieve the greatest naturalness of behaviour and emotional involvement, interaction interfaces should be as close as possible to those of the real world, engaging primarily sensorimotor skills. A positive impact has indeed been observed in the applications of gesture-based interaction [52,53] in which the visitor must perform actual actions with the body (pointing, running, jumping, grasping...) and not symbolic actions such as those performed through a device–based system, like a joystick or a game console. Several surveys conducted on museum audiences have shown that the interaction with a digital application through the body gestures, in which the user finds himself/herself at the centre of a 'performative' space, immediately generates in him/her (and in the passive onlookers as well) the impression of being involved in a playful situation, unusual within a museum. The experience is therefore mostly undertaken and lived with enthusiasm, and even difficulties do not generate excessive frustration [46,54].

2.3. Progressive Focus on Content

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With the mind and senses human beings try to approximate the reality behind the visible appearance of things. The interior of the images transforms with the interest of the perceiver: attribution of meanings grows, and memories and personal creative dimensions are associated with them [5]. The experience gradually becomes deeper and more authentic. In the extended reality of multisensory museums, the digital content associated with an object (or a group of objects) can intensify and evolve as the user retains and focuses his/her attention on it, as if to penetrate it with his/her mind and feeling.

The evolution of the contents will proceed through various steps, depending on the time of interaction, passive or active, of the user with the object. In the case of passive interaction, the persistence of the user's position in proximity of the object, or the placing of his/her hand on a sensitive surface, or the exploratory movement of the pupil with respect to the image space, will be sufficient to make the object react: this persistence of attention leads the object to manifest itself in the progressive levels of interiority.

These levels can be for instance:

1. the object is identified and made readable, e.g., through the virtual restoration of the form, if it is compromised;
2. the object is shown in its original context (built or natural), as well as the landscape associated to its original location;
3. the object's practical or symbolic use is represented, its meaning and the message it conveyed;
4. the constituent material and the execution techniques are shown, in a possible journey from macro to micro;
5. the invisible contents, hidden beneath its surface, are revealed, as censures, preparatory traits, *pentimenti*;
6. the economic and symbolic value of the object is highlighted, its uniqueness compared to other similar objects;
7. the contexts, territories, and cultures it came into contact with, during its journey in time and space, are revealed, the different meanings and values with which it was invested;
8. the signs and traumas that the passage of time has imprinted on the object are highlighted, its state of preservation and the events that have occurred;
9. the literary, prosaic, epic, poetic or dramaturgical memories related to the object are evoked;
10. other objects presenting parallels and similarities in form, meaning or value, are shown, also belonging to other cultures.

In a multisensory museum, the insight of content is expressed in audio-visual form, through the evolution of multimedia or virtual events, but also through the changing of environmental parameters, such as the intensity and colour of the light illuminating the object, olfactory stimuli, coherently with the content that is gradually manifested.

Sound participates in this progression by becoming from descriptive to evocative, gradually delving deeper into timbres and transforming or distorting harmonies.

Images and narratives for each level should be very concise and essential, the message is conveyed in evocative manner. Content develops vertically through the depth levels of which the exhibited object stays on the top, rather than being developed horizontally with too much information on one level. This approach can help the visitor to keep the attention alive and at the same time it keeps duration of the experience limited.

The object becomes alive, multi-sensory, multi-modal. It activates in the visitor/traveler an inner psychic experience, arousing thoughts, memories, fears, dreams, a sense of wonder. Thus, understanding and remembrance are strengthened.

Multimedia content can thus be used to reconfigure the map of the museum in which they are inserted in terms of attractiveness of objects, rooms, and paths. In fact, they can influence dwell times, the degree of collectivity of the experience and the level of interaction and social exchange.

2.4. Media Convergence and Combination

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The attempt to reconcile traditionally linear storytelling and interaction, real and digital content in museum spaces, free exploration and guided experience, motivating and involving the public, necessarily involves a convergence of languages. Virtual reality meets with theatre and cinema, with the paradigms of video games, with holographic techniques, mixed reality, psychoacoustics and acoustic studies. Thus, the hybridisation of media is an exciting and constantly evolving domain of experimentation.

During the museum visit digital media should dialogue with the real spaces as far as possible: even when applying gamification techniques for public engagement, the game tasks should encourage players to search for the solution in the museum spaces and among the collections (as it happens, for instance, in the classic treasure hunt) and not confine the game's dynamics and actions solely to the digital environment.

2.5. Social and Intimate Dimensions

Dialogue is a key component in the perception of authenticity and commonly the museum communication is addressed to a community of persons.

The desire to share expectations, thoughts, emotions and reaction with other persons, before, during and after the visit, contributes to the community building process.

However, dialogue can be also intimate with oneself, and it can determine in the desire to experience personal choices, actions, being true to oneself and independently from societal conditioning. For this reason, alongside the social dimension, it is important that the cultural venue succeeds in conveying moments of intimate and personal reflection, of deep contact with the artwork. Spaces must support the transition to this dimension of recollection. The alternation between intimate and collective dimensions also implies a variation of the optimal duration of multimedia contents dislocated in the museum. Of course, the duration of an application characterized by active interaction also varies according to the level of technological ability of the user. Especially for multimedia content provided in presence of the collections, along the visiting paths, it is convenient to keep the duration short and the active interaction very low, to avoid bottlenecks that could impede the visitor's flow. Even technological devices can be light, as for instance personal mobile devices, tablet, screen or projection mapping beside or onto the exhibited object. The holographic showcase, as implemented in the CEMEC (Connecting Early Medieval European Collections) European project, as a mixed reality environment containing the real artifact inside [55], proved to be excellent solution to make the museum object alive and capture the visitor's attention and enjoyment, especially if storytelling is evocative and not purely descriptive. But in the meantime, it is useful to create a spatial and thematic connection among the different multimedia stations, so to enrich the perception of the development of the story linking the different artifacts.

On the other side, solitary, intimate and reflective experiences can benefit of a dedicated space where the user can stop without pressure. In this case interaction, active or passive, can be more sophisticated and challenging.

Technologies that foster solipsistic, embodied and multisensory experience of perception will be preferred. For instance, the user can enter an immersive virtual environment, can use tangible interface to interact with smart objects integrating sensors that activate stories or multimedia events projected in the space around. Cave, head mounted display, powered exoskeleton can make contents more powerful and memorable, enhancing the sense of fear and wonder.

2.6. Mixed Reality

Mixed reality and phygital experiences are the most powerful and the most difficult to implement in a museum because they potentially bring communication at its fullest expression, not only resorting to visual media but potentially involving all senses, like sound, touch, smell, taste, even if in museums these latter two are still absent.

However, they require a respectful, credible and efficacious balance between real collections and virtual contents.

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Extended reality is understood here in a broad sense, as the coexistence of real and digital content in the same experiential space. The objects in the collection, the stories and values they express, are made explicit and enriched through digital applications; conversely, the virtual contents are substantiated and reinforced by the presence of the original objects, in a reciprocal dialogue. This alternation, or combination, produces a cognitive anacyclosis that enriches and consolidates understanding and knowledge. The term 'extended reality' therefore does not necessarily refer to systems in which the virtual content is mapped precisely onto the real content, as is the case with augmented reality or mixed reality.

Mixed reality (MR) is intended as not only a combination, but as and overlapping and collimation of real and digital content in the same 'scenic' space, so to produce a new phygital environment where real and virtual interact coherently in the space (also in real time) and are perceived as a "continuum". According to Milgram and Kishino [56], MR includes both "augmented reality", where digital information and virtual objects give more meaning to real-world scenarios, and "augmented virtuality", where real objects augment the content of artificial computer-generated scenarios.

In a MR environment, the accuracy and consistency of the overlap between real and virtual content is a crucial condition to make the perception understandable and credible. A mismatch or latency would be immediately perceived by the user as disorienting and annoying. For this reason, it is not possible to disregard a preliminary topographical and volumetric survey of the real object on which the digital superimposition will intervene, to produce a 3D model on which the virtual contents will be built, to obtain a perfect correspondence of real and virtual contents in the MR scene [55]. Obviously, the urgency of such a need depends on the type of virtual content to projected on the real objects. If it consists of textual labels, the superposition can be less rigorous than when virtual reconstructive elements are used to complete a fragmentary real object/context [57].

There are various technologies, and technical and methodological approaches to MR. Some viewers allow the user to see through the real world (*See-through AR Display* and *Monitor based AR Display*). It is also possible to enjoy virtual content superimposed on reality without the use of any device that comes between the user and the physical world, as in the case of video-projection mapping [56,57,58]. The choice of the device (for instance tablet or head-mounted display) influences not only the multisensory perception, the rendering quality, the interaction and embodiment but also the duration of the experience, the interface, the kind of media, the structure of contents, and the style of the narration. For instance, if the user is stationary in a fixed place along the path of visit, just rotating his/her gaze around him, a simpler technology with an efficient geo-localization and orientation system is sufficient. Along the path of visit, a good solution is to mark fixed points of interest in the real space where the visitor can stop and enjoy short mixed reality experiences. Storytelling should be very concise to make the experience meaningful without being redundant and forcing the user to take time out, as the mind is active on many tasks, but also to avoid queues of visitors.

If the augmented or mixed reality experience takes place on the move, the user will plausibly not use an immersive viewer but will live the experience through a 'window'-monitor display, for instance a smartphone or a tablet. Motion tracking applied to immersive devices, is an option that can enrich the sense of immersion and presence, but, along the main path of visit in a museum, it can be difficult to manage. Moreover, not all users who wear immersive such devices react positively to the solicitation of motion tracking – it also depends on the technical efficiency with which it is implemented – and for some of them it could even determine disturbance and vertigo. Hand controllers are often difficult to be used for common visitors and a support from the museum staff is necessary. Immersive devices implementing motion tracking require the user a longer adaptation time and therefore they can be used, more comfortably, in dedicated spaces. On the move, tracking the exact correspondence between real and virtual content is much more complex to manage also in terms of technological and technical implementation. The domain of cutting-edge immersive technologies of MR is very challenging from a research point of view, but not easily sustainable in

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museums, especially if they are proposed as permanent technological infrastructure. In fact, most people are not able to use them autonomously and often need the museum staff support, and even the powerful technological apparatus need a daily maintenance that usually the museums are still not able to guarantee.

The holographic showcase (Figure 1) is an example of non-immersive "see-through AR display". These systems are equipped with semi-transparent displays that allow a direct view of the world around them. The holographic showcase usually proposed in museums is based on the Pepper's Ghost effect [59], whereby the augmented content, enriching the real object exhibited inside, is projected by an 'invisible' device (a monitor or a projector) placed above the object and reflected by a transparent panel tilted at 45° [55].

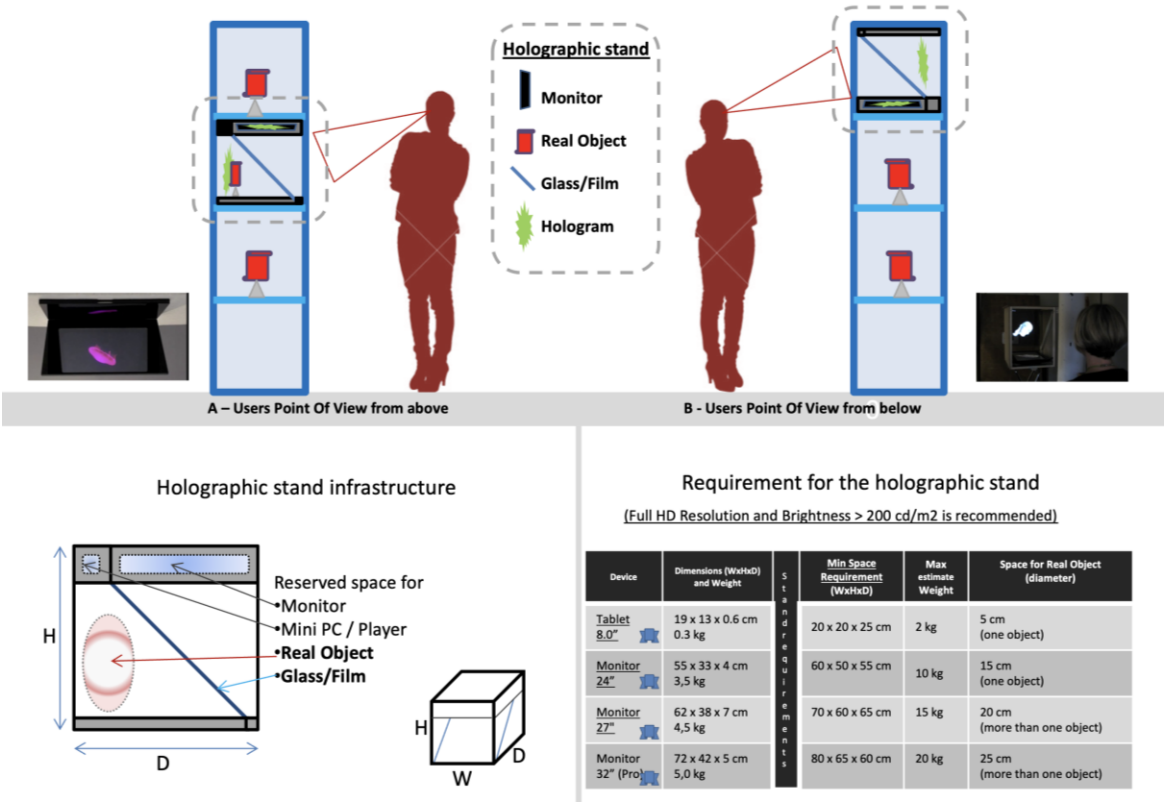

Figure 1. Overview of a holographic showcase for museums based on the Pepper's Ghost effect, and possible configurations according to the monitor position and scalable dimensions. Courtesy of Enzo d'Annibale, CNR ISPC.

A large holographic showcase gives a small group of people the opportunity to stand comfortably in front of it. A smaller one encourages the intimate experience of the individual user. Furthermore, the holographic showcase based on the Pepper's Ghost effect, if closed on the back by a transparent glass or plexiglass panel, allows the visitor to view the object from the rear, without perceiving the holographic effect (Figure 2). In this way, the installation performs a dual function: it is a holographic showcase on the front side and a canonical showcase on the back side. In terms of attractiveness and educational impact, the holographic showcase is an efficacious, easy and robust technology, sustainable in museums in the long term.

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(**a**) (**b**)

Figure 2. The holographic showcase with the real museum object inside, presented in two versions: **(a)** closed by a back black panel, as presented at the Allard Pierson Museum in Amsterdam; **(b)** closed by a back transparent glass.

Finally, in the case of projection mapping (projector-based augmented reality), lights, images ore videos projected directly onto architectural structures or objects. This technique proved to be very effective in terms of both contextual understanding and spectacular impact. In this case, the audience does not have to wear anything and does not have to physically interact with technological devices. Usability is therefore maximised. The equipment used are professional projectors, with good brightness and resistance, whose number depends on the extension of the surfaces to be mapped. The sustainability of these technologies must be carefully evaluated, especially in the case of installations designed for repeated and prolonged use.

2.7. Authenticity and Languages

The sense of authenticity is generated by the utility and credibility, progressive deepening of content, by the evolution that ensues in the mind and feeling of the user, in relation with a self-identification process. Factors determining the sense of authenticity also include expectation and, later, sharing of the received impression.

Languages used in communication have a very significant impact on the sense of credibility and authenticity perceived by the visitors. For conformism, impersonal academic languages are traditionally associated to reliability. Descriptions with technical information do not raise any discussion, as they are considered serious and objective, even if they may not meet the criteria of full comprehensibility and contextualization. On the contrary if the same cultural message is conveyed through artistic strategies or gamification techniques, people are more inclined to doubt about its certainty and they may consider it questionable, partial, perhaps childish. Of course, the artistic or evocative approach in the communication of cultural heritage, especially within museums, contains elements of risk, as it solicits differently the tastes, expectations and educational background of the audience. Examples of such different reactions and behaviours, from the sides of both curators and visitors, were observed in the case of holographic showcase mentioned above, experimented during the CEMEC project in five European National Museums. It was a mixed reality installation based on the Pepper's Ghost technique and containing the original object inside, where storytelling resorted to dramaturgical style to solicit sense of wonder and evoke the sensory dimensions beyond the pure formal aspect of the object. In that case storytelling used the same information given through the traditionally considered "scientific" supports (catalogues, panels and so on) and in fact it was realized together with the museum curatorial staff. However, they were told in first person, representing "spots" of real life, with characters performing actions and expressing emotions. In that case, most visitors remembered the contents transmitted in the holographic showcase by correctly answering the questions of the questionnaire provided after the experience, but a small minority expressed doubts about their credibility, judging them to be playful and childlike [42]. It has been observed that such a difference in the public reaction depends also on the geographical location of the museum and

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the cultural education or attitude of visitors. It was very interesting to observe that museum curators in Centre and North Europe were more flexible and inclined to accept evoking and imaginative languages to transmit cultural meanings, while visitors demonstrated a more conservative attitude. On the contrary museum curators of South Europe seemed to be more resistant, while the visitors enthusiastically welcomed a more original and exciting language and, in all cases, they felt emotionally and cognitively involved [42].

Authenticity, however, is not related only to contents but also to the whole experience and adopted languages. Can an experience be perceived as authentic even if one is aware that the proposed contents, or part of the contents, are imaginary or uncertain? Of course, this is possible because there is authenticity in the emotions that the story can elicit, and there is authenticity in the progressive understanding that our cognition is approaching a truth greater than the single uncertain element. In fact, an imaginary content can be used as a metaphor, as a tracker to another authentic content or concept. Living the experience alone or with others can also alter the perception of authenticity [19].

2.8. Sense of Wonder

As mentioned above, emotional impact and a sense of presence are fundamental in the perception of authenticity, and this is true in both real and digital experiences; unpredictable and unexpected events, emotions such as surprise, sense of wonder, involvement and happiness also generate a deep sense of authenticity. The beauty of the layout, of the soundscape, the atmosphere of the surrounding environment, the evocative style of the script, or an engaging interaction offer us the opportunity to feel alive, partakers of the magic and wondering dimension that is ongoing. Triggers of the sense of wonder can be:

- The unexpected, the unpredictable, the surprise
- The narrative that goes beyond the boundaries of simple standardised description, both in terms of language and content and in their metaphorical presentation
- Unexpected movement
- Looking with eyes other than those of everyday life
- The rediscovery of the poetic meaning of things and actions, beyond daily utilitarian and pragmatic attributions of meaning
- Multisensory dimensions, the extended reality, phygital worlds
- The sense of immanence, feeling immersed with body and mind in a real or imaginary place (embodied sensing)
- The feeling of the connection among all beings and elements surrounding us
- The feeling to be part of the whole
- The empathy
- The sense of fear
- The unexpected sharing of a feeling with other persons or lives.

There are many situations that can arouse the sense of wonder, such as walking through an ancient forest; entering a bare medieval church modelled by light and flooded by the sound of an organ; being overwhelmed by the richness of colours and shapes of a surrounding pictorial decoration; entering a dark cave; listening to the call of birds; exploring the seabed; travelling back in time; looking at a historical village and being able to grasp the intangible plots of real and imaginary lives that are hidden behind marble, stone, and concrete.

In a museum, the sense of wonder springs from the development of connections with the various levels of one's own mind, with other people, with objects, with time and territory, as if the veil that keeps things separate were to fall and their unbroken continuity were to be revealed.

It is clear how important languages and forms of representation are.

Historically the sense of wonder is considered as an important aspect of human nature, being particularly related to curiosity and the drive for intellectual exploration. Moreover, wonder can ignite an interest that goes beyond the specific experience and becomes a reason for deeper

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knowledge of a given reality [60]. Wonder, according to Plato [61] and Aristotle [62], is at the origin of wisdom and thus philosophy.

2.9. Sound and Soundscape

Acoustic design in a multisensory museum is another key factor. Sound plays a central role in the formation and development of individual and social cultural identity; therefore, sound communication is a powerful vehicle for the representation and transmission of knowledge, for experiential involvement, on both unconscious and rational level. According to Schafer, the sound environment is the result of the interaction between sound, space, and time [63]. But sound is also intrinsically linked to place, a cultural context, a body and mind, an emotion [64]. Sound is therefore essential to increase the cognitive and emotional involvement of visitors. Soundscape can evoke the cultural identity and life dimension of the contexts to which the museum objects refer, providing acoustic verisimilitude to the simulated spaces (e.g., by conveying meaningful sounds, music, timbres and harmonies of traditional instruments or songs, vocal techniques), in connection with the original places where they were practiced. Such sound compositions may be the result of the application of psycho-acoustic principles (as it happens for example in cultural video games or cinema) or scientific simulations of acoustic spaces obtained through mathematical models [65].

Various disciplines, such as archaeology, art history, anthropology, musicology, acoustemology, ethnomusicology, acoustics, architectural acoustics and archaeoacoustics are intertwined and combined in the study of sounds from the past, as shown by the interesting studies published in 2020 in the special issue of the journal Acoustics "Historical Acoustics: Relationships between People and Sound over Time", edited by Francesco Aletta and Jian Kang [66]. In addition, acoustic design in museums can also enhance the sense of authenticity because it strengthens the collective dimension of the experience, fostering in the audience a process of perceptual and emotional synchronisation towards the content, a common vibration, a sense of cohesion and shared meaning [67].

All this implies that the sounds are well recorded, and that the museum is equipped with good technology for high quality audio reproduction and management. In the author's experience, a bad audio quality immediately betrays the unprofessionalism of the audiovisual product, more so than the imperfection of image. Of course, if the audio is derived from an original historical recording, the authenticity value of the source prevails.

Unfortunately, within museums there is still resistance and a lack of attention towards audio technology. Sound and music have always been considered of minor importance, if not disturbing. Insufficient attention is paid to sound technologies for single or collective listening, and their day-to-day management. Few professionals, few investments, few infrastructures have been introduced in museums, and little research has been conducted into the acoustic design of museum spaces and sonic heritage [68]. Yet audio formats and technological solutions are manifold and can meet all the needs of audiences and curators, even with the help of sensors to control their activity and pervasiveness: stereo, dolby digital surround, mono, directional sound, and binaural. An article published in 2021 by the same author of this contribution [65], includes a deep discussion about methodological approaches and sound technologies for museums.

Of course, the acoustic properties of the museum space, and consequently the sound design, must facilitate sense-perceptive processes, considering also the need of people with visual or hearing limited abilities, as recommended by the European guidelines "Accessibility Requirements for ICT Products and Services. EN 301549", In this regard, to be as much inclusive as possible, audio contents should follow some basic rules: orally recited texts should be accompanied by subtitles and translations in the sign language, that users should be able to activate autonomously. Besides, audio description of visual contents should be accessible for visually impaired persons, activated by the user on a predefined specific audio channel of the device, and avoiding interference with other audio solicitations.

2.10. Tangible User Interfaces (TUI)

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Tangible user interfaces, 3D prints for tactile exploration, and capacitive and tactile sensors can facilitate accessibility and engagement, and they can enrich the multisensory cultural experience. TUIs are based on the tactile perception and exploration of an object to grasp the physical properties of its surface (such as material, elasticity, viscosity, flexibility), volume, form and understand its function and meaning. The use of a replica of an original object (printed in 3D from a digital reproduction or handcrafted) is particularly useful for blind people that cannot otherwise perceive the original object, which is untouchable in most cases [69,70]. From many years, the National Tactile Museum Omero in Ancona (Italy), has been promoting the "the beauty of touching, of establishing an emotional relationship with things and the pleasure of contact with different materials, the joy of discovering sensory nuances, possible uses and combinations. A beauty that can be touched, a beauty that overturns all the canons of the purely visual approach to art, to rediscover a new yet primordial relationship with nature" [71,72,73].

When linked to multimedia events, the tactile interface is usually equipped with sensors which recognize the user's touch and determine a status change in the system, allowing multimedia content to be started.

The tangible interface can also consist of three-dimensional interpretation of two-dimensional pictorial works, where high, medium and low reliefs correspond to foreground and background elements in the 2D image. In the HELP European project, carried out in 2003 by the CNR in collaboration with the Scuola Normale Superiore di Pisa [74], this solution was experimented to help blind users to perceive and interact with a 2D painting. The audio comment was triggered by the contact of a miniaturised three-dimensional tracer that the blind user wore on his/her finger, which tactilely 'explored' the form, enabling the user to mentally reconstruct the work. The audio contents were of two types: 1) sounds corresponding to the colour of the painting in that point (according to synaesthetic principles), 2) very short audio descriptions of the touched element.

However tangible interfaces are not necessarily replicas of real objects. They can also derive from creative design, as several examples of interactive installation proposed in museums can demonstrate [75,76,77,78,79].

The technology supporting the interaction with a TUI can use two different types of sensors:

1. conductive paint and/or piezoelectric sensors: This electrical method involves direct contact with the object by the user. It is based on the conductivity of certain materials/pigments of which paints are made, and on so-called 'capacitive' sensors that can detect touch on their surface by generating a change in electrical capacitance. These solutions require a computer, a programmable input-output electronic boards equipped with microcontrollers such as Arduino or Raspberry PI [80,81], capacitive sensors and/or conductive paint. Objects are electrically wired to the board's connectors to detect their capacitance. The advantage of this technique is the high sensitivity to touch, ease of operation and simultaneous use by several hands; the disadvantage is the alteration of the physical surface properties of the paint-treated object and the decay of the conductive properties of the paint over time.
2. Computer vision: this method [82,83] allows the user's action to be intercepted even without direct contact with interactive surfaces, for example by recognising the action of a hand in a specific area. For these solutions, a computer (with higher performance than in the electrical method) and a camera equipped with an infrared depth sensor (such as Kinect, Leap Motion) are required. The advantage of this technique is that it does not alter the surface physical properties of the object, the disadvantage is the accuracy of the input, which might be slightly lower.

The result of active stimulation by the user is the reproduction of audiovisual contents, for which a monitor (or video projector), audio speakers and a scenic lighting system are required. In general, users should be facilitated by lights, lines or colours, patterns in relief circumscribing the interactive areas within which they must operate and focus their attention, making it easier for them to identify objects and interfaces.

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TUIs should also be located at an appropriate height and should be easily accessible for users on wheelchair.

Information on the TUI, such as captions describing the different elements, should also be translated in Braille.

2.11. Digitisation

The sense of authenticity, in museums, is particularly relevant when dealing with digital 3D representations of real objects, in both their today and past possible appearance. In the first case an accurate and validated digitisation procedure is needed, in the second case it is important to respect criteria of reliability, truthfulness, transparency of sources and of interpretation processes that supported virtual restorations and virtual reconstructions [84,85].

A digital object, considered as a reproduction of a real object, represents an approximation of its form and appearance, and makes it possible to preserve its knowledge and memory even if the original gets lost, provided that this digital object is obtained through a rigorous methodology, as accurate, detailed, faithful, neutral and complete as possible.

In addition, through 3D printing techniques, a material replica can be obtained from the digital one, which can represent some of the properties of the lost original object and can be manipulated or relocated to restore a fragmented or missing context.

However, as mentioned above, by virtue of its immateriality, digitisation should not be limited to the formal approximation of an object as such. It is useful to extend the concept of digital object to that of "digital content", i.e., an expressive unit endowed with form and meaning, that can communicate both the function, context and cultural value of the object and the information necessary to understand how the digitisation process was carried out (metadata, paradata).

The realisation of a digital model following such criteria of objectivity and truthfulness makes it possible to associate reliable integrations of form (virtual restoration), contextualisation in relation to the original place for which it was conceived (virtual reconstruction), values and meanings attributed to it throughout history (semantic characterisation, narration).

The digital twin is even more: it is a virtual simulation of a physical entity including not only the appearance and meaning but also the behaviors of the object in relation to the ecosystem. This is made possible using sensors, actuators, an internet connection and software control allowing to exchange information between the virtual (cybernetic) and physical components, to make tests, monitoring, maintenance in real time [86]. Heritage Digital Twins are understood also as digital replicas of CH objects linked to all associated knowledge, interpretative levels, attributions of meaning, relations with other items, interactive processes and digital documentation [87]. Digital twins can integrate the Internet of Things, artificial intelligence, machine learning and data analysis. They can create digital simulation models that update and change when their physical counterparts change [88].

These actions are highly desirable to foster in-depth knowledge and understanding of the cultural asset, useful for prevention and protection, and for valorisation addressed to the public. Digital content can thus be the starting point for learning scenarios aiming at diverse audiences. A new economy could develop thanks to shared and conscious digitisation practices, such as the creation of digital libraries and services.

The digital object, accompanied by the necessary information, can thus become part of virtual collections, enriched by storytelling, following procedures of 'loans' between museums. Virtual collections can complement real collections already on display, complete them in cases where apparatuses or contexts are physically dismembered and scattered in several places, establish connections or comparisons among objects of various provenance but linked by a common theme.

The digital model should hopefully adopt the principle of open science, especially when the digital resource or its derivative is used for non-commercial purpose, such as study and scientific research. Digitised data could be released, even for a fee, by governmental institutions for profit purpose, for the benefit of creative cultural industries.

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This scenario requires an improved curatorship able to manage the continuous renewal of the museum communication strategy.

Finally, the application of FAIR principles [89,90] to digital cultural heritage, shared and promoted at European level, is an essential condition for sustainable life cycle of digital resources, capable of generating new cultural, social and economic value. Data, in fact, should not only be produced, but also updated over time, shared, properly re-used, feeding the creation of new cultural content. According to this perspective, the adoption of FAIR principles is at the basis of the creation and maintenance of quality data, capable of guaranteeing an easier interaction between the actors that, in different ways, play an active and creative role in the transmission of cultural heritage.

2.12. Representing the Invisible

Digital documentation, representation and valorisation of museum artifacts of particular interest, could include both visible content and elements that are not visible, hidden in the structure or in the sub-surface levels of the artifact. This can be the case of the preparatory drawing of a painting, or elements that served to the execution process and remained incorporated in the structure, materials coming from a restoration work, or alterations resulting from censorships. The characterisation of the chemical–physical–biological nature of the materials at the different stratigraphic levels can reveal interesting information related the execution technique, the conservation history and the present state of conservation, and it helps to understand the material value of the object [91]. This approach could be innovative, aimed at creating a multidisciplinary experience with the artifact and its production context, craft skills and workshops. All these data could be integrated in a multidimensional model of the object (a 3D model to which the fourth dimension of depth can be added and explored), taking into consideration tangible and intangible values.

For such a multidimensional model, superficial information of an artifact can be captured via laser scanner, or via photo cameras and then elaborated through structure from motion and photogrammetric techniques. Instead, invisible content associated with the sub-superficial layers can be acquired through non-invasive diagnostic techniques and sensors, such as 1) pulsed thermography, which produces images in the medium infrared range, able to reveal hidden elements or detachments beneath the surface, 2) X-ray fluorescence, 3) Raman spectroscopies, 4) hyperspectral imaging, and multi-band imaging techniques as ultraviolet, 5) Vis-NIR reflectance, 6) reflectography [92]. These techniques are chosen and combined according to the material aspects to be investigated. Then, all the relevant information can be mapped onto the 4D model as “annotations” and as informative/semantic spots. Data interpretation and interrelations can help in the reconstruction of the complex story of the artefact. The annotated multidimensional model can then be explored through interactive installations of virtual reality or mixed reality [92].

2.13. Virtual Reconstructions and Authenticity

A virtual reconstruction in archaeology entails a digital restitution of an artefact at the time of its creation or at its successive phases of use. However, in this domain, virtual reconstructions are approximations, tools for better understanding the past and not statements of reality [93]. Usually they are possible reconstructions, especially when dealing with lost ancient contexts. Virtual models are just simplifications, resulting from a selection of information, useful for interpretations [94]. A virtual reconstruction, in fact, can help scholars to understand structural solutions, working as a verification tool, and it can always be updated in the light of new discoveries.

Again, in archaeology, a virtual reconstruction is usually the result of an integration of bottom up and top down approaches: the first one refers to the digital documentation and analysis of what is still remaining on the site; se second one consists of the collection, study and interpretation of historical, iconographic, literary sources, architectural rules and proportion theories, including comparison with similar case studies [93]. Virtual reconstructions let the public better imagine and understand the original context of the exhibited artifact, its function, value and properties, giving

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concreteness to abstraction. As it was assumed at the beginning of this contribution, the final goal of virtual heritage is the interaction process, the semantic value and the cognitive incitement that develop from this interaction.

Rendering techniques, contents and metadata, visualization technologies, user interface and investigation tools depend on the different audiences they are addressed to, even if they should always follow scientific consolidated criteria. The experience will be more analytical, with a focus on the structure and its elements, construction materials or executive techniques, with connection to related databases, in the case of an expert audience [95]. On the contrary it will be more dramatised, sensory, narrative or playful, in the case of a non-expert public that must be introduced to the cultural context, the way it was used, life dimension, and historical background. In this case holistic approach and embodiment prevail over analysis, exploration tools and metaphors will be calibrated accordingly, while maintaining continuity and coherence between scientific source, knowledge and communication [96].

Today the realism achieved through digitization and computer graphic techniques can easily lead the public to believe that a virtual reconstruction is truth, especially when presented in a museum and created by a renowned author. In fact, a critical aspect with this kind of reconstructions regards scientific transparency. In most cases it is very difficult to distinguish what is original and what is hypothetical because sources and interpretative processes are not declared, nor made accessible.

Truthfulness requires a verification process. The London Charter in 2006 [97] and the Seville Principles in 2011 [98,99] tried to discipline authenticity and reliability of virtual reconstructions in archeology, recommending some rules and good practice to make explicit, plausible, findable, sustainable, repeatable the sources and the logical processes of interpretation. Otherwise, the risk is to diminish virtual reconstruction to mere sensationalism and fictional scenarios.

Starting from those criteria many developments and applications followed in the research domain [100,101,102]. For instance, many solutions have been found to distinguish, in reconstructive models, the different degrees of reliability of single elements or portions, that must be stated through graphic expedients that allow the recognizability of the interpretive intervention [103,104].

Also, in the creation of a narrative related to cultural heritage, the story must be plausible and credible, being the museum an educational cultural institution. Certain and circumstantial contents regarding the artifact will be combined with plausible and probable ones, the latter pertinent to its cultural context. To suggest the reliability of each segment of the audiovisual narrative, the author has introduced, since 2021, a kind of visualisation that recalls the methodology traditionally applied to highlight the reliability levels of the different elements in architectural virtual reconstructions [17]. This visualisation assigns a different symbolic colour to each level of certainty/uncertainty, based on the available sources (Figure 3). Thus, in the colour code of the narrative content reliability, these symbolic colours can be superimposed on the final rendering to give scholars an immediate overview.

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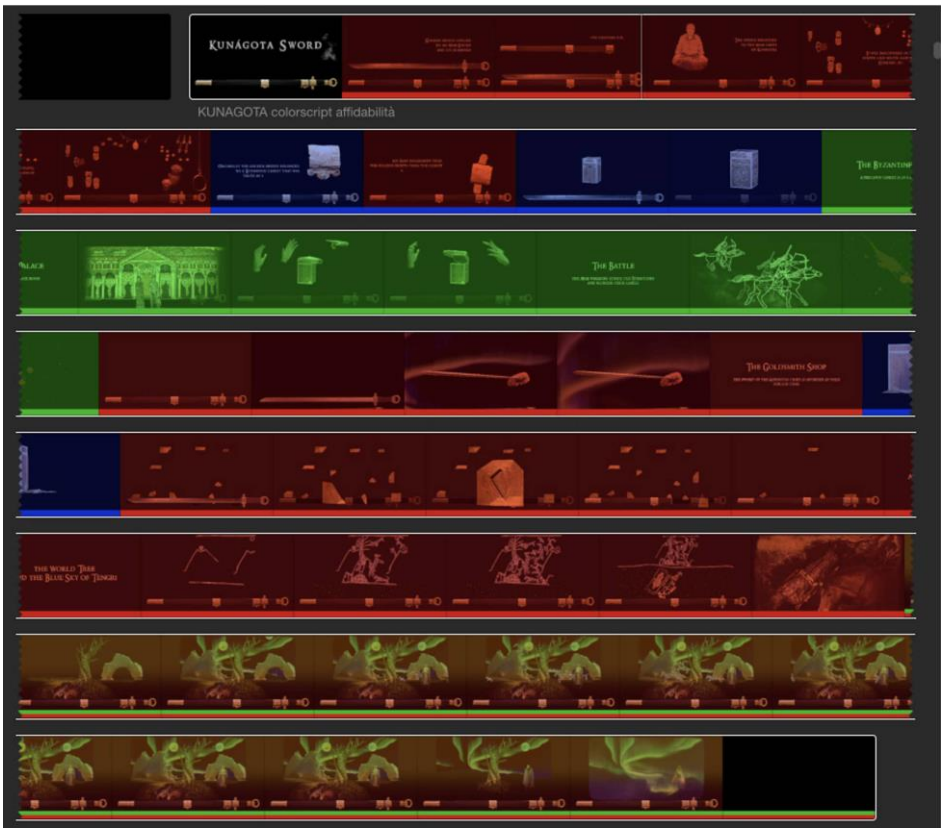

Figure 3. Movie timeline referred to the storytelling of a museum object, with symbolic colours suggesting the different levels of reliability of the narration. Red: certain, based on archaeological evidence; blue: very probable, based on cultural–contextual evidence; green: evocative, based on historical and cultural background. The movie in this example is referred to the Kunagota Sword and can be seen at: https://vimeo.com/236305120.

In museums applications sources and logical interpretative processes, which have been followed to create virtual reconstructions, must be referred. They can be integrated in the main application for the general public, as in-depth analytic layer [105,106], or they can be proposed in a separate, complementary application for expert visitors [107].

2.14. Embodiment

A key concept in the experience is "the sense of presence" [34], that is related to cognitive and emotional involvement of the user in the surrounding environment. Humans open their mind to the world through intuitive experience; sensing and emotions are fundamental in the life experience and in the self-identification process, they are the engine of knowledge and development of the individuals (Kabat-Zinn 2001).

"Sensing" and feeling "embodied" in a cultural context means the capacity to enter in contact with those elements that let us "recognize" something and move our emotions. For instance an evocative landscape, an ancient bare church resounding with a choir, and organ and trumpets, a multisensory museum have the power to activate a perceptual phenomenon that allows us to feel an intimate sense of happiness and enjoyment, difficult to verbalize [31].

The embodied cognition approach affirms that mind and body are not separate and distinct, as Descartes mistakenly thought [108], but that our body, and the brain as part of the body, contributes to determining our mental and cognitive processes. Some classical philosophies, such as Platonism, Augustinianism, Cartesianism, Kantian conception of the intellect, revealed a tendency to o make the mind totally other than the body, without considering their interrelationships, or even their unity), with a persistent devaluation of the body. Reflection on the corporeal and embodied aspects of cognitive and mental processes has taken place since the 1980s in various disciplines, from cognitive linguistics to artificial intelligence, from neurobiology to phenomenology, and has become central in

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philosophical research on mind and cognition between the 1990s and the first decade of the 21st century. The theory of the embodied mind was presented on biological grounds in the classic study by F. J. Varela, E, Thompson, and E. Rosch, [52] with a focus on conception of phenomenology [109].

The theory of the extended mind proposed by A. Clark and D. Chalmers [110] focused on the constitutive and causal role of the physical environment in the formation of mental processes, pushing the mind not only beyond the brain but also outside the skin and the body itself, at the centre of environmental interactions but also of social relations with other cognitive agents. G. Lakoff and M. Johnson pointed out the component of the operational aspects of corporeality in the origin of mental states and language, starting with the use of linguistic metaphors. In neurobiology, the role of the bodily component in the origin of emotions, consciousness and empathy was highlighted [111].

According to Daniel Mellet-d'Huart Knowledge in virtual environments comes from "*enaction*" and it is built essentially on sensory motor skills and direct experience in the 3D cyberspace [112]. In a museum conceived as an extended reality environment, and in virtual reality as well, embodiment can arise from:

- immersion in an interactive multidimensional space;
- multichannel and multisensory stimulation;
- graphic realism;
- tangible user interfaces, object manipulation;
- creative body interaction and freedom in movements;
- mid-air gesture based interaction;
- feedback from the environment in real time to user's actions and exchange of information with the environment;
- possibility to modify the layout/the setting/the assembly of objects in the space;
- engaging and emotional storytelling, dramatization, cinematographic and theatrical techniques;
- augmented reality;
- emotional and meaningful soundscape;
- interaction with other users;
- personal evolution in the digital ecosystem, [113];
- randomness and unexpected events.

The latter influence positively the sense of presence, because they enhance the realism of the interaction and the complexity of decision processes, as it happens in the real life. For this reason, artificial life is often introduced in videogame, and considered a promising frontier in the domain of virtual heritage simulations as well [114]. In fact, through the experimentation and interpretation of new relations/differences we can process information, learn and develop an appropriate epistemological approach towards ourselves and the surrounding world.

Besides, the emergence of new social paradigms and media enhancing cultural interactions among people induce the creation of specific social platforms for Cultural Heritage that encourage an active participation of many stakeholders. There is an increasing request of digital frameworks open to the communities for the accessibility, study, participatory and sustainable management of cultural resources and assets [115]. In recent years, many museums have created their 3D extension in the metaverse, where interactions are free and more creative, especially open to the co-creation of contents, multiplication of perspectives, informal representations and meanings. In the metaverse users can recognize themselves through avatars or through their real image while acting in real time. The embodied communities live in a 3D space; users can perceive, meet, dialogue, touch objects, build and transform the surrounding virtual environment, make and simulate hypothesis, perform actions following a common a purpose. The virtual collaborative environment is thus conceived as a performative space, [116]. Of course, the level of the engagement inside the cyberspace is an essential condition to create embodiment.

2.15. Profiling Target Audience

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"Personas" are fictional characters but based on real data derived from field research. Each "persona" represents a specific type of audience of a service: it is therefore an archetype that brings together users with similar characteristics. Referring to this typology through a name and an image helps to make profiles concrete and refer to them in a practical and shared way. "Personas" help designers, curators and ICT experts more aware of the importance of user research and a user-centered approach [117].

Data about the public refer to the collection and analysis of information regarding visitors and potential visitors, their attitude and preferences. These data help museums to understand their audience, enhance visitor experiences, and tailor their services.

Data gathered from the public can be demographic information (gender, age, provenance, education, occupation), behavioural information (visit frequency of museums, main interests within the museum, visitors' movements and pathways, aptitude for solo or group visits, level of attention, timing), information about satisfaction, engagement with digital contents, ability to control digital devices and digital interfaces, level of interaction, demand for assistive technologies, aptitude to share the experience with others. User profiling can be done by classical manual mapping methods, through the use of sensors and, more recently, through artificial intelligence.

Manual mapping involves conducting surveys by recording data directly at cultural sites or obtaining statistical data from tour operators and agencies of tourism promotion. In museums and cultural venues interviews can be carried out directly on visitors.

Some kind of information can be collected more objectively using sensors. For instance, visitor movements in a museum can be tracked using Radio Frequency Identification (RFID) [118,119], beacons [120,121], and Wi-Fi and other infrared or Bluetooth sensors which enable automatic features to be activated as users pass through. These ones are various sensor systems composed of transmitters and receivers that assign an electronic identity to things surrounding us and form the basis of the Internet of Thing (IoT). They allow objects, people and content from the real and the virtual worlds to be connected, to create smart and inclusive environments capable of adapting services to the needs of those who visit or work in the museum. An example was the application, "eXspot", at the Exploratorium, a science museum in San Francisco, California [122]. Other examples of application of such systems in museums can be found in [120].

As mentioned above, "personas" make it possible to identify the characteristics, needs and desires of potential users. Artificial intelligence (AI) is revolutionising the field of marketing. Companies are harnessing its potential for analysing and targeting their audiences, achieving better results in a shorter timeframe and on large amount of data (big data). Through market research and real data, AI can create detailed profiles, modelling "personas" in terms of origin, age, gender, goals, motivations, interests, aptitude, needs, habits, movements, friendships. Promotional and orientation campaigns will be increasingly targeted on the individual, and no longer on population groups. This information derives from what we enter into the network via social media, online database entries, or dialogues with ChatGPT. Artificial intelligence uses this data and connects them, analyses them, and it can predict what the 'consumer-user' might like and proposes it to him/her. The cultural market (of which museums are part) can make use of these new developments to personalise their marketing messages and to create targeted strategies, creating customised and satisfying contents for their target "personas".

The implications of these developments are many, interesting and difficult to predict. On the one hand, the user is framed and treated according to the stereotypes and homologation logics of the consumer society, becoming a "consumer". Personal habits and characteristics are mapped and traced, with a consequent compression of the privacy level. Basically, all people matching a certain profile will receive from AI similar answers to the same questions. By now everyone accepts, more or less consciously, that an artificial intelligence decides what they will learn from journals and informative digital media. Recommendation algorithms, which were created to make it easier for users to find the information that best suits their personal interests, have also learnt over time to suggest the messages that best meet the platform's needs: i.e., to keep people engaged with the

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platforms as long as possible, to gain their attention as intensively as possible, in order to resell that time and attention on the market for personalised advertisements. The risk is to provoke the spread of various forms of social network addiction, by using also fake news and 'deepfakes', (a technique for synthesising the human image based on AI), produced by other artificial intelligences. AI does not behave objectively but tends to benefit the companies that produced it. One wonders what impact this technology will have on the economy, society, religion and politics. Artificial intelligence can strongly influence knowledge and the relationship with truth, behaviours, social goals and tendencies towards polarisation, collective processes of decision making, and the relationship with freedom. On the 17th of February 2024, the Digital Service Act came fully into force in Europe [123,124]. This is the first organic regulatory intervention in the world that protects users of online platforms against the abuse of recommendation algorithms.

Which use will the tourism and cultural industry make of AI in the next future? AI could enhance human creativity, being able to store, create new associations of thought, networks of human and non-human knowledge, and thus generate new, unexpected narratives about the world. It is possible that through an intelligent, independent and generous use by museum curators and scientists of the opportunities that artificial intelligence offers us, a richer, more creative and inclusive cultural communication could be developed, in which the sense of authenticity and the opportunities for individual expression, through the irreducible values of culture and imagination, can be preserved.

This is a dilemma in our society. In the field of cultural transmission artificial intelligence is a big issue for the future. We must balance optimism with awareness of the risks that can come in many forms, either through unintended uses of new technologies or through malicious actions seeking to exploit areas of vulnerability.

The doubt is that, even if AI can certainly be used to offer many useful services to the citizens, it can, at the same time, turn into a weapon of manipulation and mass homologation of public opinion, now firmly in the hands of a few, gigantic, private software companies. In this regard, it is interesting what Mario Draghi wrote in his report on competitiveness presented on the 16th of September 2024 to the European Commission, where he indicates a European strategy towards AI [125]: <<*A critical issue for Europe will be integrating new technologies like artificial intelligence into our industrial sector. AI is improving incredibly fast, as the latest models released in the last few days show. We need to shift our orientation from trying to restrain this technology to understanding how to benefit from it. The cost of training frontier AI models is still high, which is a barrier for companies in Europe that don't have the backing of US big tech firms. But, on the other hand, the EU has a unique opportunity to lower the cost of AI deployment by making available its unique network of high-performance computers. The report recommends increasing the capacity of this network and expanding access to start-ups and industry. Many industrial applications of AI do not require the latest advances in generative AI, so it's well within our reach to accelerate AI uptake with a concerted effort to support companies. That said, the report recognises that technological progress and social inclusion do not always go together. Major transitions are disruptive. Inclusion hinges on everyone having the skills they need to benefit from digitalisation. So, while we want to match the United States on innovation, we must exceed the US on education and adult learning. We therefore propose a profound overhaul of Europe's approach to skills, focused on using data to understand where skills gaps lie and investing in education at every stage. For Europe to succeed, investment in technology and in people cannot substitute for each other. They must go hand in hand*>>.

2.16. Evaluation of the User Experience in Museums

It is not easy to create content and experiences to satisfy the heterogeneous museum audience. It is very important to study museum audiences in advance - establishing where they come from, their degree of cultural and technological literacy, the age groups to which they are most likely to relate- to design the best types of experiences.

It is also very important to assess and understand how, within cultural venues, the audience experiences culture. The aim of these evaluations is to explore the effectiveness of exhibition design,

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the attractiveness and usability of digital technologies, the level of engagement, social and individual behaviours, the educational impact of media, and finally the visitors' ability to critically process and remember content. One of most efficient method the authors has experimented [41] is a structured, multipartition analysis on various user targets, based on three steps: observation, filling in questionnaires and guided scenarios, i.e., tasks that the evaluator asks the user to perform, while interacting with the digital application, to understand whether he/she is able to control the system.

To be indicative of a trend, the data collected must generally be derived from a sample of several tens or hundreds of visitors, as this is the only way to compare the expectations of ICT designers and developers with the actual reaction of the public.

Feedback from the public helps to verify, understand more deeply and improve the effectiveness of the content, the languages and media adopted and the interaction interfaces, the technological solutions, the layout of the space, the routes, the duration of the experience, the group dynamics, and of course the relationship between the real collections and the digital content offered in the museum. What emerges is useful not only for researchers but also for curators and museum staff as it allows them to gain experience and awareness and to be better prepared to deal with the critical issues and extraordinary opportunities that the combination of real and virtual contents can offer.

2.17. Use of Ai in the Cultural Heritage and in Museums Sector

Artificial intelligence can be used in the cultural heritage and museum sectors for different purposes.

In the User Research studies, it can support:

- target audience, users understanding;
- design brief.

AI-driven sentiment analysis is a powerful tool to analyse and interpret visitor comments as natural language processing can gauge satisfaction, emotions, and key themes, providing valuable insights that would take months of manual analysis to be achieved.

Software like QoQo [126], UserDoc [127], and Design brief Generator [128] use AI to generate UX personas, journey mapping, information architecture, summaries, sitemap and wireframes, clusters of similar ideas on the base of common themes and patterns; they provide tools to organise requirements with folders, labels and relationships or aimed at format conversion.

In the domain of big data analyses and improvement, artificial intelligence and machine learning can offer the possibility to automate and sometimes enhance a number of manual processes involved in the collection, processing and metadata of texts, 2D images and 3D models. As Europeana's recent survey on the role and impact of AI in the digital cultural heritage sector showed [129], there are numerous projects underway with the aim of increasing the efficiency of:

- digitisation, 3d models fixing, denoise;
- resolution-enhancing processes;
- classification;
- restoration or reconstruction of CH assets;
- deep learning and text analyses (transcription services, keyword extraction);
- accessibility and automatic indexing of data;
- archival management.

The interest in these practices is often linked to the search for new ways to facilitate the production and exploitation of digitised collections, given the potential of AI technologies to work on large amounts of data. Interpretability and generalisation of AI results are emerging issues.

In the generation of virtual scenarios, virtual objects, and digital collections there are also several potentialities and uses of AI. New artificial intelligence or light field rendering algorithms [130] make it possible to generate and process 3D data or to represent real objects through techniques that go beyond direct instrumental measurements on the field. These techniques focus on representing all visual properties of a scene without generating an explicit and measurable representation (as in 3D digitisation) of the scene itself. Through these approaches, from several static

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images, it is possible to construct a 3D representation and generate images from new viewpoints. Technologies such as NeRF (Neural Radiance Field, based on neural networks) [131] or Gaussian splatting [132] are examples of these techniques. These techniques take photographs as input and initially perform the same orientation step as a normal photogrammetric digitisation. However, at present they are mainly used for visualising 3D scenes rather than for metrically rigorous documentation.

The application of artificial intelligence and machine learning neural networks, combined with the human knowledge provided by the experts, also offers a significant opportunity to improve the quality of metadata and their use on a large scale, as, for instance, expected in the European Collaborative Cloud for Cultural Heritage [133].

AI can support also in the generation of storytelling and audiovisual contents.

These solutions belong to the domain of natural language processing. A Natural language is any ordinary language that occurs naturally in a human community by a process of use, repetition, and exchange without conscious planning or premeditation. It can be a spoken language or a sign language, and it differs from constructed and formal languages such as those used to program computers or to study logic.

Computer have been provided with the capability to **process data encoded in natural language** (Natural language processing - NLP). NLP is a machine learning technology that gives computers the ability to interpret, manipulate and understand human language, thanks to the huge amount of voice and text data coming from various communication channels such as text messages, social media, news, video, audio and more. To automatically process this data, NLP software analyses the intent or sentiment in the message (through speech recognition algorithms, text classification, natural-language understanding), [134,135,136] and respond to human communication in real time (natural-language generation) [137].

The origin of natural language processing dates to 1950s when Alan Turing published on magazine “Mind” an article titled “Computing Machinery and Intelligence” [138], which proposed a test (known as “Turing test”) to demonstrate the linguistic and thinking capacity of a machine as a criterion of intelligence. It is a test of a machine’s ability to exhibit intelligent behaviour indistinguishable from that of a human, through the simulation of a conversation. The conversation was limited to a text-only channel, such as a computer keyboard and screen, so the result didn’t depend on the machine’s ability to render words as speech, nor on the machine’s ability to give correct answers to questions, but only on how closely its answers resembled those a human would give [139]. The breakthrough came when AI learnt to reason according to a probabilistic approach, in the 1990s, and the decisive improvements was enabled progressively by the availability of data, supercomputing capacity, large data centres for cloud computing, new algorithms designed in the new millennium. In 2022 GPT (Generative Pre-trained Transformer) [140,141] was released, with the ability to put together sentences with excellent syntax and perfect punctuation. The new generation of Chat GPT, recently released by Open AI and equipped with ‘Voice mode’, is able not only to speak, but to whisper, laugh, sigh like a human being, giving all expressive and sentimental inflections to speech and approaching any topic from various perspectives.

We can imagine that in the near future 3D AI characters will be capable of interpreting not only our questions but also our emotions and reacting accordingly, providing information in multiple languages, conversing with us, expressing emotions in turn, performing actions, similarly to the humans, thus making human-AI interaction more natural and empathic. Digital humans are already being developed; an example is given by the Algho [142], a No-Code conversational AI platform composed of proprietary technologies to create Virtual Assistants in business processes. A growing market will develop, and many uses can be envisaged of such digital humans, as multilingual assistants, instructors or companions, or as LIS interpreters.

But is it really intelligence? According to Viola and Biase [124] today the answer is no. Intelligence means the ability to synthesise, to invent something from nothing and not from something that exists, the ability to assimilate and then create something totally new. Language,

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although extraordinarily powerful, is a communication-oriented simplification of human thought. All the cognitive activities of humans are not included in language. Today's machines cannot, therefore, be considered intelligent.

Generative artificial intelligence algorithms do not make choices based on value chains or conventions, but only probabilistic choices.

The machine imitates human language, not by doing any logical operation in deductive sense, but by setting up a linguistic operation. It considers 1) the rules of linguistics as probable combinations and 2) the data it has at its disposal to concatenate words. These capabilities are not inventive but are emulative. The machine has no critical sense, it just assembles words correctly. Although the machine will certainly develop further, gaining the ability to connect logical concepts, this scenario is not possible at present [124]. Today not only newspaper articles are increasingly written by AI, but also travel and tourist guides, and they are often reviewed by other IAs. Today, authors using AI are those who write large amounts of content because AI let them to save time. Perhaps asking for suggestions and ideas instead of answers is the best correct method to use AI, while declaring human or artificial authorship of content is a must. Copyright is indeed another open issue that needs to be regulated. AI tools can provide creative teams also with stories, screenplays, casting and character profiling, sounds, images and movies, voices. Prompts provide the seeds to help ChatGPT deliver consistent, relevant and engaging content based on the relevant use case. Practically, prompts are textual instructions or images that we provide to AI, guiding it towards the desired output. AI consists of neural networks that rely on billions of images it has been trained on, to render a true-to-life image, by means of different algorithms, in particular GANs and Diffusion Models [143]. The number of tools for creating images has multiplied day by day; some are free (as OpenArt or Canva) [144,145], some requires payment in their advanced version (as OpenAI DALL-E) [146], some are websites (as Midjourney) [147], others are stand-alone software (as Adobe Firefly) [148].

A similar approach id adopted also by AI for video and sound generation: available platforms translate text prompts into video or musical compositions. The description of such platforms is beyond the scope of this article, which is limited to providing a general overview of the AI potentialities in the creation of cultural, narrative and multimedia content, which is also applicable to the museum field.

As AI technology advances, the museum industry has been increasingly integrating AI to enhance both visitor experiences and operational efficiency. In 2016, an exhibition curated by a group of anthropologists at the Musée Du Quay Branly in Paris presented Joe Berenson, a robot playing the role of an art critic, created by Denis Vidal and robotic engineer Philippe Gaussier [149]. But the robot was easily influenced by the public, as its objective was not to say what it thought about the artworks, but to sample and determine, through the artificial intelligence algorithm, the reaction of people observing the artworks around. It was an excellent tool for mediating with the public and a valuable aid for conducting surveys on the composition of museum and art gallery audiences.

Artificial intelligence also plays a role in audience engagement. In 2018, Google's Arts & Culture launched Art Selfie, a web app that used facial recognition to match users' selfies to portraits in museum collections [150]. AI applications have been conceived and designed for museums, to bring historical figures to life through chatbots using their writings, archives and oral histories [151].

In 2019 the EuropeanaTech Community established a GLAMs Task Force (Galleries, Libraries, Archives, Museums) to do a horizon scanning exercise and investigate the role and impact of artificial intelligence (AI) and machine learning (ML) in the cultural heritage sector. The final report [129] provides an overview of a survey that received 56 responses from cultural heritage and research institutions. The purpose was to create an informative basis upon which facilitate the innovative, ethical and sustainable growth of AI technologies within cultural heritage. These institutions are currently increasingly interested in AI technology, although it is perceived as being too time consuming for their organisations, with benefits coming only from the application at a large scale.

From the results it emerges that:

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<<(Meta-)Data quality is the topic for which people have more practical experience with AI (29.1%), followed by Knowledge Extraction (29.1%), Collections Management (21.8%), Discovery and Search (21.8%). (Meta-)Data Quality is also the topic in which most people are "very interested'' (65%), followed by Knowledge Extraction (59.3%), Collections Management (61.8%), Discovery and Search (60.0%). The least interesting topics for our respondents are Machine Translation (20.0%" not interested"), followed by Audience Analysis (12.7%), Crowdsourcing and Human in The Loop (10.9%) and Creative or Engagement Projects and Initiatives (10.9%). […]

Additional areas suggested by the respondents that can be considered interesting for them or for which they have experience with are: Layout Recognition, Photogrammetry Automation, Production of 3D Content, Data Extraction (e.g., *Optical Character Recognition (OCR) and Handwritten Text Recognition (HTR)), Music Information Retrieval, Collection Content Analysis, Semantics (Linked Data, Knowledge Representation), and Visual Recognition (object, subject, color of image/video). GLAM institutions are most interested in using AI for facilitating the exploitation (and to some extent, the production) of their digitised collections. By digitising their cultural heritage objects, they can improve the accessibility of these objects to the public, who might be able to access them* via *online portals. Once the objects are digitised, their metadata needs to be enriched for improving findability and searchability […]. Several interviewees pointed out the limitations of commercial AI tools, in relation to the complexity of the complex nature of CH data and use cases. […]. The consulted professionals agree that AI has great potential within their organisation and more broadly in the GLAM sector. However, AI and Machine Learning (ML) have not been applied widely so far. The attraction for the skilled, often technical people, to work in the CH sector might not be strong enough yet. The complex nature of the collections is challenging, as the data in this domain possibly involve multiple symbolic, allegorical and contextual interpretations>>.*

3. Results

This section will present some applications and projects representative of the principles expressed in the previous sections in relation to multisensory experiences in museums that enhance accessibility, understanding and visitor engagement with contents. The author of this paper played the role of project coordinator or participant in each of them.

3.1. CNR Anniversary: 100 Years of Science

In 2023 the National Research Council, Italy's largest scientific research institution, celebrated 100 years since its foundation. On this occasion, various initiatives were organised to retrace and present its history, the impact of scientific research on civil society in Italy and around the world, and the future perspectives and challenges. From October 2023 to September 2024 the CNR headquarters in Rome opened its doors to citizens, students, tourists, researchers and their families, offering a multimedia experience that was narrative, playful and educational at the same time [152]. A multi-sensory installation positioned in the entrance main hall has been conceived and realised following the principles of inclusiveness and participation, and stimulating the visitors' curiosity through tactile interfaces, multi-projections, sensors, and multimedia (Figure 4).

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Figure 4. The installation *100 Years of Science*, 2023, on display at CNR's main entrance hall, Rome.

The designers, in fact, wanted not only to convey scientific content but also to interest, surprise, convey the beauty and passion for research, and make people understand that research is a value for society. Therefore, authors worked on an effective audio-visual narrative, not following a disciplinary categorisation.

As research is an open, interconnected and accessible space, the metaphor that was chosen is the celestial sphere, an open space, constantly rotating and without boundaries. Users can explore the constellations, their stars and planets by means of an ideal astrolabe, an ancient astronomical instrument through which the humans oriented themselves when observing the sky and navigating across the sea. By moving the astrolabe, the star map is rotated, bringing each constellation into the centre of the screen.

The constellations represent the 10 keywords, that is CNR's major research challenges: sustainability, biodiversity, ecological transition, digital transition, clean energy, circular economy, life sciences, health, cultural heritage, peace and scientific diplomacy. The meaning of each keyword is told in a simple introductory video. These challenges require the convergence and interaction of many disciplines, making research exciting and open to continuous encounters and interactions.

By entering a constellation, it is possible to approach the introductory video and then the stars representing the most representative projects of that keyword. The projects as well are presented through short videos (around 1,5 minutes each one), realized integrating the resources coming from the research groups. Projects make it possible to get in touch with research environments, places, objects, people (Figure 5).

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Figure 5. The installation *100 Years of Science*, 2023, at CNR, Rome. In foreground the tangible interface and the world map showing dynamic connections among research centers participating a project; the central screen in the background is showing a narrative movie related to a selected project, accompanied by translation in Sign Language.

The software system was structured to be easily implemented in the future with new projects, giving visibility to ever new research.

As research is also an interconnected space, the networks between laboratories and research centres in Italy and around the world, working together on various projects, are dynamically gathered from a database and visualised on the planisphere projected in the centre of the table.

Finally, this is an accessible space: the entire installation and the space in which it is located are designed to encourage participation by all people. Sensory and tactile interfaces, sloped planes and material layout favour physical access; translations into English, Braille, LIS and IS, and subtitles favour sense-perceptual and cognitive access. A large CNR research group has worked on these aspects, and the choice of shapes, colours, contrasts, lighting, and sounds also supports this principle.

The Installation, implemented by the Institute of Heritage Science (ISPC) of CNR, is therefore composed by [152] (Figure 6a and 6b):

- a wooden structure designed according to physical and ergonomic accessibility criteria, to facilitate wheelchair users,
- the “astrolabe”, a rotating console, through which the visitor can navigate the celestial sphere; it consists of 11 relief shapes (tactile but not interactive) with symbolic figures representing the constellations-keywords and the history of CNR; these figures are very simple and stylised and can be recognisable also by blind or visually impaired people; they are also identified by Braille captions;
- proximity or stop sensors that allow the system to understand when the user is present and when he/she activates a constellation or keyword;
- a tactile slider allowing the user to navigate the constellation and activate projects;
- three screens positioned in a semicircle, to involve the audience in a panoramic view, on which the slowly rotating celestial map is visualised.

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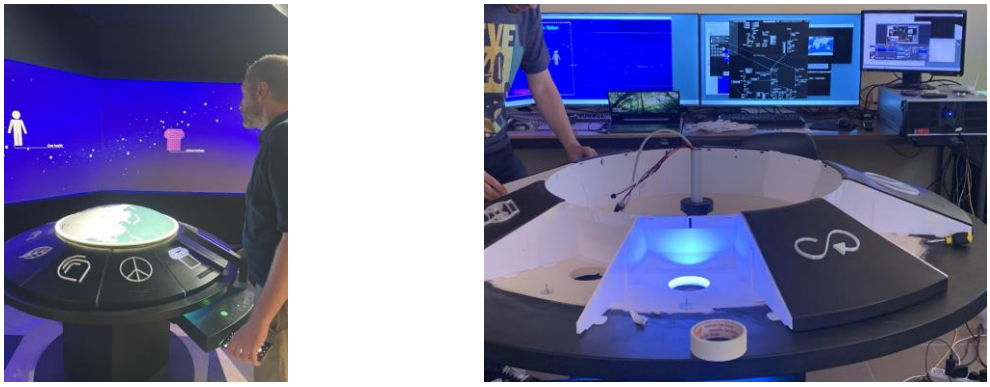
In addition, multimedia content is also accessible from a similar web app that can be started anywhere, via mobile devices, from one's own PC or from a kiosk, without the need for installation [153]. The online experience is based on the open source framework ATON [154,155] developed and maintained by CNR - ISPC.



(**a**) (**b**)

Figure 6. The installation *100 Years of Science*, 2023: **(a)** main rotating interactive interface with 3D printed elements corresponding to constellations-keywords; the slider allows to enter a constellation and explore its stars-projects; **(b)** the implementation phase developed at CNR ISPC.

3.2. The Codex 4D Holographic Showcase

In 2022-2023, the project "Codex4D: 4D journey into the manuscript" was developed by the Institute of Heritage Science at CNR and the University of Rome, Tor Vergata, thanks to funding from the Lazio Region (POR FESR Lazio 2014–2020). The project is concerned with the definition and testing of a methodological pipeline for the digital documentation and 3D exploration of both visible content and elements that are no longer visible or hidden in the structure of ancient codices, e.g., text parts buried in the binding and stratigraphies of the illuminations, as well as characterisations of the chemical, physical, and biological nature of materials. Therefore, 3D models of some manuscripts were realized, to which the fourth dimension of depth was added [91,92].

The approach is innovative, aimed at creating a multidisciplinary experience with the manuscript inside virtual and mixed reality environments, taking into consideration tangible and intangible values: form and structure; content and meaning; materials, execution techniques, and state of conservation. Surface information is associated with the visible spectrum of light, RGB, captured with a standard photo camera. RGB images were also used to produce a photogrammetric model of the object, through structures from motion techniques. The invisible content related to the sub-superficial layers was acquired via a thermal camera and consisted of images in the medium infrared range. The relevant information has been contextualised and visualised as "annotations" on the virtual multidimensional model, or as additional textures applied to the model.

The interpretation of such amount of data can help to reconstruct the complex story of the artefact, including the significance of written and pictorial content, craftsmanship, workshops' "modus operandi", conservation history, and cultural relations.

The project was developed on three main case studies at the Angelica Library in Rome: 1) Ms 1474, De Balneis Puteolanis, a poem by Pietro da Eboli, dated 1258/1266; 2) Ms 1102, Divina Commedia by Dante Alighieri, dated 1325/1350; 3) Ms 459, Libro d'Ore, a prayer book for secular use, dated at the beginning of the XV century AD.

As the ancient manuscript is usually difficult to communicate to visitors (it is handwritten, in a disused language, impossible to leaf through, and problematic to perceive in poorly lit showcases), the authors tried to create new approaches also in communication strategies, to arouse curiosity and keep the audience's attention.

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Several outputs were developed in the Codex 4D project, that differ in (a) type of users, (b) context of use, and (c) type of experience, and, therefore, adopting different communication styles.

A multimedia web site [156] was designed for in-depth educational and scientific purposes, in which the Codex 4D project, the methodologies and technologies employed, and the results of the research are recounted.

An online virtual-reality environment (Web App, accessible from the web site), was designed for the scientific visualisation and analytical exploration of the manuscript 4D model, intended for more expert users; a demo can be seen at [157].

A holographic showcase, based on Pepper's Ghost technique [59], was designed as a mixed-reality installation for museum and library audiences. As the holographic showcase resembles a small theatre, provided with lights, scenography, buttons, sensors, research data are presented through an emotional and playful narrative.

The showcase, in fact, introduces a dramaturgical storytelling: a narrator character, played by an actress filmed in green screen, lives in the illuminations, and tells that world from the inside. She is as small as the illuminated figures, performs actions and uses tools to enhance the perception and understanding of the codex (Figure 7).

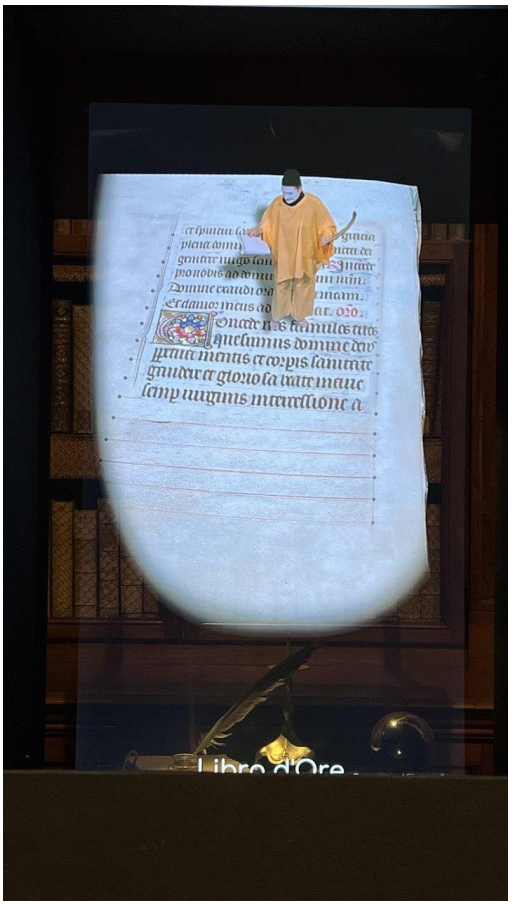

Figure 7. *Codex 4D* holographic showcase with the narrating character performing actions on the manuscript, 2023-2024.

In the holographic showcase, the 4D model is again enriched with annotations dealing with the iconography, iconology, materials and techniques, and state of conservation, which the user can explore by moving his/her hand on the model, through simple gestures. Motion capture is managed by the Leap Motion sensor [158] and contributes to raising the user's curiosity and engagement.

In this way, the Codex 4D project aims not only to increase the scientific knowledge of the manuscript but pushes the languages of scientific communication into new experimental territories to attract and intrigue new audiences, introducing gamification and dramaturgy. This achievement

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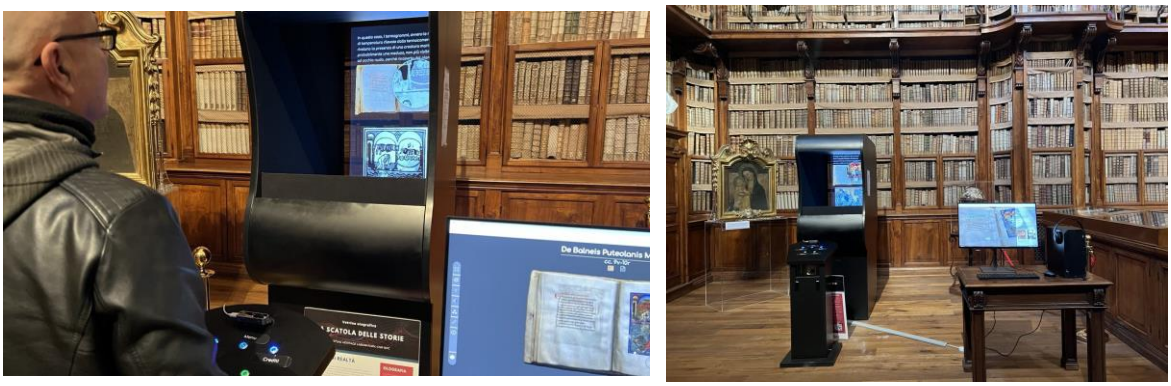
was made possible by the integration of many different competences into the team: paleographers, codicologists, art historians, conservation scientists, physicians, chemists, biologists, 3D modellers, experts in communication and user studies, computer scientists.

The Codex 4D holographic showcase was presented to the public for the first time at the exhibition "Languages of Heritage Science: from Micro to Macro," at the Genoa Science Festival (Villa Principe, 20 October–1 November 2022). On that occasion, a survey was conducted to evaluate the experience and impact of the showcase on the public, represented mainly by high school and university students, families, experts, and individual and group visitors. Results are presented in [159]. Contents have been enriched for the new exhibition set up at the Angelica Library in Rome, from 10 November 2023 to 8 February 2024 (Figure 8). In this venue, the holographic showcase was shown next to the original real manuscripts which were displayed in a dedicated showcase aside, and close to them an installation with the web site and the web app was presented as well.

In October 2024 Codex 4D project won the Heritage in Motion award [160], in the category Virtual and Augmented reality, with the following motivation: «This innovative project has been recognized for its groundbreaking work in making fragile historical manuscripts accessible to both scientific and general audiences, embodying the essence of the "heritage in motion" through innovation and preservation».



(**a**) (**b**)

Figure 8. The *Codex 4D* holographic showcase in the historical Angelica Library in Rome, 2023-2024: (a) exploration of invisible sub-surface levels; (b) contextualization in the room beside the Codex 4D web app and the showcase with the original books.

3.3. e-Archeo Human Interface

Commissioned to ALES SpA by the General Secretary of the Italian Ministry of Culture, and realized in 2021-2022, e-Archeo is a major national multi-channel project for the enhancement of 8 archaeological parks, from North to South Italy, through digital and multimedia technologies. The sites were chosen to represent the multiplicity of cultures that characterised ancient Italy - Greek, Etruscan, Phoenician-Punic, Italic - later integrated under the common Roman hegemony, while maintaining some distinctive features: Sirmione and Desenzano on Garda Lake, Marzabotto, Cerveteri, Alba Fucens, Velia, Egnazia, Sibari, and Nora.

Several virtual reconstructions and multimedia applications were realised for different audiences, with a scientific, narrative and emotional approach, with particular attention to technological sustainability and accessibility, and under the banner of open science principles.

The purpose of the partnership, composed of government institutions, CNR ISPC, 10 universities, 12 creative industries, Rai Cultura, and accessibility experts, is to strengthen the capacity to work together in the valorisation of Italy's cultural heritage. CNR ISPC played a decisive role in the overall multimedia design of the interventions and in coordinating the executive production.

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Multimedia applications are usable by the public in different ways and in various moments of the cultural experience, both in situ and remotely, through online applications and site-specific installations [161]. The project provides various levels of representation and narration of contents, various tools and communicative styles to illustrate the different contents: to the scholar it provides all the information to follow the reconstruction process of the various environments (levels of reliability, sources and interpretative processes) (Figure 9); to the visitor it provides narratives adopting a more attractive and sometimes dramatised style.

Figure 9. *e-Archeo* project, 2022. Virtual recontruction with rendered with symbolic colours suggesting the reliability levels.

Accessibility strategies as TUI, and Universal Design principles have been applied to allow everyone, including people with visual, hearing and motor disabilities, to enjoy the content, especially in the case of Cerveteri site (Figure 10).

In October 2024 the project won the Grand Prix Möbius in the category 'Mutant publishing', dedicated to "Immersive experiences of tourism and culture", with the following motivation: "'*for its high strategic value, its focus on openness, quality and accessibility of data, and for the plurality of dimensions involved, including the tactile dimension*" [162].

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Figure 10. *e-Archeo Tactile,* 2022. Tangible interface and accessible multimedia at Sala Mengarelli in Cerveteri.

The outputs of the project are as follows and they are described in detail in [161]: 1) e-Archeo 3D; 2) e-Archeo Voices; 3) e-Archeo Tactile; 4) e-Archeo HI—Human Interface; 5) e-Archeo Video; 6) e-Archeo Website. The e-Archeo Website [163] offers access to web apps and to the Zenodo e-Archeo collection [164]. As all the datasets have published in Zenodo under the Creative Commons licenses, they can be re-used by site museums, to create new multimedia experiences for their visitors, on the sole condition that they are released under the same license.

In this paragraph the e-Archeo Human interface experience will be shortly described, as it offers avenues for discussion not addressed by the previous case studies.

The e-Archeo HI® application was developed for the archaeological contexts of Cerveteri and Sirmione, starting from scientific data collected by the universities and proposed in a non-specialist narrative. The installation is on public display at the Archaeological Museum of Sirmione and the Cerite National Archaeological Museum in Cerveteri. A character, represented by an actor acting in a costume, on a 1.1 scale, dialogues with the users interactively and narrates the archaeological area and its history. He also illustrates some of the museum's exhibits from the archaeological context.

In Sirmione the narrating character is the poet Catullus, who links his name to the site although he never lived in the villa we see today. In Cerveteri the character is Vel, owner of an important ceramics workshop in the town. The user interacts with the narrating character having the impression of conversing with him, vocally or by selecting topics via tablet, thanks to a narrative node structure.

e-Archeo HI® is placed near the showcases containing artefacts of great interest for the narrative (for instance in Cerveteri Museum, the Crater and the Kylix of Euphronius); the lights are dynamically switched on and off on the artefacts, synchronising with the narrative led by the virtual character. The digital installation thus functions as a 'narrative hub' or an 'extended reality' experience, because it has not an autonomous life, independent from the museum collections, but,

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instead, it dialogues with the users and the physical objects, which react by lighting up as they are mentioned in the narrative (Figure 11). The overall experience lasts about 20 minutes.

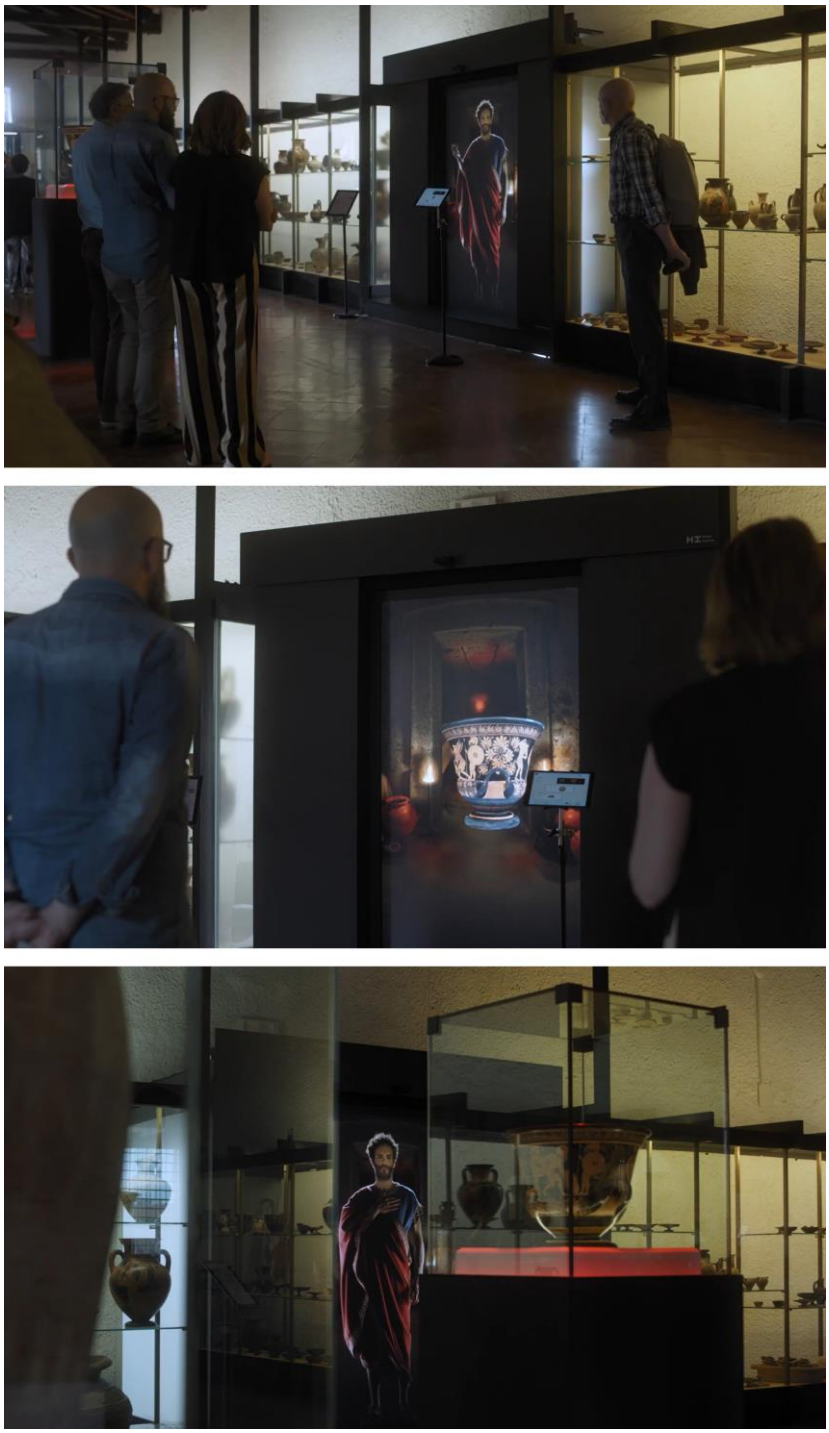

Figure 11. *e-Archeo Human Interface*, 2022 at the National Archeological Museum in Cerveteri.

3.4. The Innova Patrimonio Project

One of the challenges of our time is to make the peripheral territory and small ancient villages, which constitute open-air museums of the European identity and traditions, no longer static and closed places, where it seems that many things are being lost, but rather spaces of cultural convergence, creative energies and exchange. This can be encouraged by the interaction of the resident population with artists and researchers, and thus by the contamination of the local cultural tradition with new personal perspectives and actions.

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The Innova Patrimonio project [165] funded by the Lazio Region (POR FESR Lazio 2014), has created an innovative model of narration of the peripheral territory and rural areas, considering the case study of the Sabina region, north of Rome, crossed by an ancient Roman consular road, via Salaria. The major experimentation involved the village of Fara in Sabina (RI), founded in the VI century AD, located on the top of a hill, where fewer than 200 residents live.

In a process of narration and representation of an ancient village, we asked ourselves which strategy could be preferred to arouse motivation, interest, affection in both inhabitants and visitors. Certainly not the traditional and impersonal descriptions of itineraries and monuments, but, on the contrary, an original narrative built through interaction and co-creation processes, based on a convergence of personal stories, languages and perspectives. For a community the identification of itself and its daily-life environment within a narrative is a reason for immediate interest and attention. At the same time, however, curiosity must be activated by a new glaze showing those familiar places in a different light, as spaces of symbolic and unexpected representations.

Thus literature, cinema, theater, video-projection mapping, 3D graphics, mixed-reality come together in this unusual representation of the village, in which the community looks at itself and at its "habitat" with new eyes, which react in unexpected ways. Thus, Fara Sabina becomes a town "made of stone and marble but also of wires, curtains and angel wings", recalling Calvino's tales "Invisible Cities" [166].

Actors from a major theater residing in the village, playing in the role of characters created over many years of shows, portray local stories, walk down alleys and squares, cross gardens and cellars, enter homes. They narrate the stories, the life and transformation of places over time, following an authorial script. The active participation of the population adds meaning to this playful re-invention. The story springs from the encounter between the eclectic and surreal invention of the artists and the concrete contribution of the inhabitants, with their experiences, private spaces, opinions, habits, and passions (Figure 12). The traditional description of itineraries and monuments is replaced by a dramaturgical representation of stories, ways of life and imaginary dimensions that constitute the unique character of the village.

To make this magical dimension more alienating, virtual appearances and digital projections on urban scale have been created

Figure 12. The *Innova Patrimonio project*, 2021. A theatrical charatcter, perforiming the role of the guide accompanying the visitor through Fara in Sabina, is surprised by the unexpected appearance of an ancient Sabine throne in the main square of the village.

Objects from the Sabine and Roman civilizations, preserved in the Civic Archaeological Museum of the village, have been digitized in 3D and projected onto the exterior facades of the buildings. They parade, brought in the hands of today inhabitants, who were also filmed and projected onto the facades, as successors of ancient populations and present custodians of those artifacts (Figure 13).

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Figure 13. The *Innova Patrimonio project*, 2021. Video projection mapping on the architectures of the village square of Fara in Sabina. Inhabitants parade with archaeological objects preserved in the local museum.

The most valuable object is the two-wheeled chariot of the Sabine prince of Eretum, decorated with historiated bronze sheets, coming from a monumental tomb of the 6th century B.C. discovered in the nearby necropolis of Colle del Forno. Its virtual appearance in the sky of Fara and then its entry into the museum, in presence of the entire population, marks the symbolic epilogue of the story (Figure 14). The chariot becomes a symbol of friendship and luck. Through these visual metaphors, access to cultural heritage is thus expanded outside the museum, to promote a wider integration within society.

Figure 14. The *Innova Patrimonio* project, 2021. The return of the ancient Sabine chariot of Eretum in the sky of Fara in Sabina, at the end of the story.

The various stories have been entrusted to short films that can be activated from an interactive map. The research has produced 1) an open platform through which users can access the itineraries but can also modify them and customize their cultural visit, 2) a web app, 3) a native app, 4) a website [167], 5) site-specific installation for the museum, and 6) a 1h 30′ film. A platform based on the VVVV software [168] was also experimented, to manage the direction and transmission of online

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multimedia events in real time, within a VR environment: in the 3D model of the square of Fara in Sabina, a video-projection mapping in real time was performed on the architectures. At the same moment, on a virtual stage located in same virtual square, live interventions of people were played. Public could connect to this event and enjoy, as it was done in occasion of the review meeting of the project.

The project was delivered to the Lazio Region and presented to the Municipality of Fara in Sabina. What has been achieved is a scalable and exportable model for the valorisation of other ancient villages, to stimulate creativity and, hopefully, to improve tourist attraction [169, 170].

The project, carried out during COVID-19, gave life to new educational processes, aimed not only at inhabitants, students, tourists, but also at creative industries and scientific institutions working in the enhancement of cultural heritage, inventing new approaches that combine science, art, knowledge and technology.

This repeated encounter has resulted in an emotional and creative ferment that has gradually spread to involve the entire local community. Its first effect is the overcoming of distrust, the desire to build together and the strengthening of social cohesion. Innova Patrimonio, realized during the pandemic, was an opportunity to share an imagination, experience beauty individually and collectively, and promote it as a social value.

3.5. The PERCEIVE Project

The PERCEIVE (Perceptive Enhanced Realities of Colored collEctions through artificial Intelligence and Virtual Experiences) European project [18] starts from the need to better perceive, understand, preserve and communicate colored artworks. Colored works are extremely fragile and vulnerable, as color tends to degrade and change until it is lost. For example, the colors of textiles fade in just a few decades; ancient statues today retain very few traces of their original garish colours; similarly, the colours of analog photography can be subject to substantial fading due to aging.

At the same time, the PERCEIVE project aims to conceive and develop strategies which could be employed to maximize the visitor experience with a variety of colorful digital collections, as well as natively digital artworks, and to transmit and communicate them in the most efficacious and correct way to future generations. The concepts of “sense of care” and “sense of authenticity,” are two core concepts of the project.

The project is still being developed and expected results include:

1. the reconstruction of the original perception of the colored artworks through simulation tools and the production of on new digital images;
2. the prediction of the future evolution of colour changes;
3. the use of the obtained results in tools, services, and interactive prototypes to be accessed on site and online;
4. the elaboration of methodological guidelines for the exhibition of the coloured collections;
5. the creation of a design toolkit addressed to designers, educators, and curators, aiming at creating new multimedia, VR and AR applications.

The project aims to employ artificial intelligence and machine learning to automate several manual processes for reconstructing the original colour, thereby facilitating and speeding up the work of scientists and creative industries. A primary requirement

is feature extraction, which is an essential task in the process of image analysis. As computing power is increasing and acquisition techniques are improving, the feature extraction process could be carried out by AI-based techniques. Initial results show that learnt AI-based descriptors, on average, outperform traditional hand-created descriptors. However, these techniques revealed a disconnection between the mathematical representation of extracted features and any meaningful parameters perceived or understood by humans [171, 172] The risks associated with the use of AI that the PERCEIVE project aims to mitigate are: 1) lack of shared methods and tools; a) absence of AI adoption for 3d or more complex collections; b) limitations related to the training dataset and lack of a shared data source; c) use of local infrastructure; and d) little or no evaluation of the results. The

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project, started in 2022, lasts 36 months and it represents a good occasion to investigate the potential of artificial intelligence in this frontier domain.

4. Discussion

The museum should be the place where the visitor lives perceptual experiences that are unique and not equally repeatable outside the museum. In other words, the virtual visit that one can make inside the museum should not offer the same content, with the same modalities of fruition, that a smartphone can offer in any other context of use.

The nagging presence of *smartphones* in every moment and place of our lives risks compromising the opportunity that museums can seize from multimedia: bringing spaces to life, animating them, dramatising them, recreating a sensory dimension behind the exhibits. Delegating the entire digital offer to the *smartphone*, asking the visitor to constantly direct his/her gaze and interaction on this small display, risks weakening the exceptional nature of this experience. This is undoubtedly an easy and functional solution, since it evades problems of daily management of technologies; however, it is not an exciting solution to lead the visitor into a lively experience.

Multimedia content can be used to reconfigure the map of the museum in terms of attractiveness of the objects, rooms and routes since they influence the permanence times, the degree of collectivity of the experience, the level of interaction and social exchange.

The design of the museum experience must consider both digital content and the exhibition layout: real and digital should dialogue, to polarise the visitor's attention and emotion on the place in which he/she is currently immersed.

The great effectiveness of extended and mixed reality consists in the fact that real and virtual no longer exist in separate spaces and times but communicate not only conceptually but also 'physically', becoming synergetic components of our perceived and experienced space. Reality, thanks to the coherent superimposition of the virtual, becomes multi-layered, stratified, in continuous potential transformation, a 'canvas' on which forms and meanings can be reconstructed, representing interpretative or imaginative contents. Through mixed reality it is possible to give new light to those aspects or meanings of the artwork that have been erased or are no longer perceptible, mainly due to conservative or ideological reasons (*damnatio memoriae*, or modernisation) or due to the artist's modifications. These contents can be documented by diagnostic analyses revealing the material aspects hidden under the surface, and they can be visualized through a digital projection onto it. A new convergence of sciences, arts, languages and technologies is possible today, and the fusion of the real and the virtual seems to prefigure the perceptive and cognitive dimension of our daily life in the future.

Another fundamental aspect of exhibition design is the correct relationship between virtual content and real collections: the virtual should not overpower the real. Visibility, clarity of display and evidence of the concept to be expressed, harmony, relaxing conditions of use, but also aesthetic and cognitive stimuli, are all aspects that need to be balanced correctly to generate a feeling of well-being. Lighting, acoustics, seating and order in the flow of visitors are essential to create a comfortable environment. Certain 'iconic' elements or objects that convey the main concept transmitted by the digital installation can be replicated in their material aspect and placed nearby, or original artefacts included in the digital storytelling they can be highlighted, as in the case of the e-Archeo Human Interface project, to recreate an experiential context.

Physical and virtual enjoyment thus become part of the same knowledge process, combined in conveying the material and immaterial value of the cultural asset: they reinforce and complement each other, according to a holistic and multifunctional approach.

One of the objectives of the research should concern the experimentation, within real, digital or extended reality contexts, of different narrative languages and levels of interaction, aimed at the construction of a story and its transmission/sharing with a diverse audience. Different narrative forms and modes, (linear or interactive, predefined or co-created, transmitted by 3D characters or by human narrators), may in fact prove to be more effective in certain contexts and with particular

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subjects, through certain transmission modalities. For this purpose, various professionals should interact: cultural heritage experts, writers and scriptwriters, directors, set designers, graphic designers, musicians, user experience designers, psychologists, cognitive scientists, neuroscientists, doctors.

Finally, the technologies used within museums should be easy to use, robust and sustainable over time, because their maintenance is one of the most critical aspects even today. The adoption of criteria and practices for digital data management is of paramount importance, as it is functional to their long-term maintenance and development. Compliance with the FAIR principles is a fundamental requirement among which the interoperability and metadata of digital contents is of particular importance. The publication of data, if produced thanks to public funding, in accordance with the Open Science principles is a prerequisite for the life cycle of public information, consistent with the general guidelines of Horizon2020 Programme (Horizon 2020 Open Research Data Pilot and Data Management Plan) and Horizon 2021-2027 [173, 174].

The growing instances of participation and sharing of cultural information, also linked to 'citizen science', co-creation and crowdsourcing programmes and initiatives are expression of the unstoppable digital transition that is underway. It is therefore necessary to adopt rules, services, tools and good practices so that this great amount of digital heritage can be subject to quality control, can generate new cultural, social and economic value, and cannot be dispersed.

Collaboration with the school sector is very important. Curators and educators should be stimulated to involve students in the creation of new content that can enrich the museum experience, bringing new perspectives, exchange of knowledge, new storytelling and languages.

5. Conclusions

The creation of a multidimensional and multisensory experience in a museum, understood as extended reality in which analogue and digital are harmoniously integrated, implies a complex design. In the paper, methodological aspects were discussed, and case studies were presented, which can help to assess:

- who the current or potential museum visitors are, and which their expectations are;
- how the museum can help them meet their needs, offering them a profound and multisensory experience of comprehension and well-being;
- what strategies can be adopted to attract their curiosity towards the contents, but also to retain attention and focus it progressively, so as to foster emotional involvement, critical processing and remembering;
- how to integrate real and virtual content in the museum space to create extended realities;
- which are the principles for good storytelling and useful interaction;
- how to increase embodiment in analogue and digital spaces of experience;
- which good practices should be followed in cultural heritage digitalization, how to codify and express levels of trustworthiness and reliability of virtual content;
- how to represent and transmit the invisible aspects of the artworks, hidden beneath the surface;
- how to increase the sense of authenticity of the cultural experience;
- how to create inclusive and accessible museums;
- how artificial intelligence works and what perspectives it opens up in the field of study, creativity and transmission of culture, especially in museums;
- how to encourage social exchange while at the same time tugging at the innermost chords of the individual who comes into contact with art and the objects of our history;
- the importance of the link between museum, territory and communities;
- how to ensure the life cycle of digital resources.

Therefore, there are so many challenges and activities to forge communication, adaptable to a heterogeneous audience, with the ultimate and unique purpose of transmitting culture. Digital technology, and specifically virtual reality, cannot replace the real experience of visual and bodily perception of the original objects, which are embedded in the museum context and atmosphere. The

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museum experience turns out to be not linear but cyclical, with emotions playing a crucial role at every stage [175].

Mixed reality and phygital experiences are the most powerful and the most difficult to implement in a museum because they potentially bring communication at its fullest expression, not only resorting to visual media but involving all senses, like sound, touch, smell. However, a respectful, credible and efficacious balance between real collections and virtual contents is recommended. Physical and virtual contents reinforce and complement each other, thus becoming part of the same knowledge process. They convey the material and immaterial value of the cultural asset and can increase the authenticity of the experience. The expressive quality of the multimedia content needs to be very high, both from an aesthetic point of view and in terms of historical documentation and cognitive value.

The primary task of digital and multimedia along exhibition routes is to multiply the levels of perception and symbolic reconstruction of the meaning of cultural objects, to increase their communicative potential and make them more comprehensible and accessible. Through digital media it is possible to integrate their shape and volume (virtual restoration), to simulate their context of provenience (virtual reconstruction), and their thematic connections (storytelling). In fact, the virtual allows us to give form to abstraction, to represent something that does not exist, that is no longer visible or testable. Although a restoration, as well as a virtual reconstruction, can present elements of uncertainty with respect to the real original state of the object, they are nevertheless fundamental vehicles of understanding: without them, the abstract mind could be induced into greater error, that is in interpretations far from any historical plausibility.

Another task that multimedia technologies should perform, in and out the museum, is the multichannel dissemination of cultural information, i.e., the ability to convey content through diversified languages and technologies intended for users with a variety of cultural backgrounds, needs, technological abilities, origins and ages, including persons with disabilities, for whom the difficulties of accessibility to the original cultural asset are amplified. Audio-visual representation, interaction, and gamification within cultural venues can also attract young audiences, involving in collaborative experiences and in the creation of a shared *storytelling* that makes them feel participants and protagonists.

Such a perspective makes it necessary to place alongside the traditional curatorial teams - consisting of experienced archaeologists, art historians, architects and conservators - also professionals who remained so far outside this context, such as writers and scriptwriters, directors, set designers, graphic designers, lighting experts, musicians, user experience designers, digitalisation experts, sociologists, and computer scientists.

As discussed, machine learning and generative AI are opening new scenarios in management practices, in image processing, pattern recognition, text analyses, natural language processing, decision making, and in the dissemination of cultural heritage. These scenarios need to be understood and well driven, through the integration of new professional skills. Artificial intelligence can increase the accessibility of museum content through multilingualism, virtual assistants and sign language virtual interpreters, and by providing information about the artworks. Before AI, it was impossible to answer any curiosity or question of visitors. The answers were necessarily static and predefined, and this could lead to minor public involvement. With the development of generative AI, a major challenge is emerging how to control the data used by AI to prevent misinformation to visitors. It is crucial to inform users about what they can realistically expect from AI. More than elsewhere, in cultural institution it is mandatory to consider the ethical implications of AI, to ensure that these algorithms are used in a responsible and inclusive way.

Transparency is the first key point: users must be informed about where and how AI has been used, and where information comes from. Intellectual property is another ethical issue to be considered, together with fair representation of contents across different cultural contexts, avoiding offensive interpretations or marginalization of people. Finally, AI should be used as complementary

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to the human experts, enhancing and not replacing the role of the museum staff in the visitors' engagement.

The combination of culture and technologies can produce new economies, but culture must not become a mere product of the market. Technology can help humans to automate, connect, control processes remotely, shape creativity, but with the aim of affirming a new humanism that puts the human being at the centre and without burdening him/her with anxieties.

5.1. Future Perspectives

In future researchers it will be useful to investigate further which factors mostly influence the sense of well-being, involvement, motivation and embodiment in museums.

For an evolution of museums towards multisensory communication, the involvement of all senses is desirable: touch, smell, taste, in association with the audio-visual experience, in real as well as in VR and MR environments. For this kind of experience, digital technology and robotics are not yet ready to offer usable, agile and effective solutions. However, physical objects with sensors, which can be experienced tactilely, dispensers of scented or tasty essences can easily be integrated into the interaction space.

An often missing experience for museum visitors, apart from specific activities addressed to schools, is the practice of making, using one's hands to go through some of the processes that led to the creation of the artworks.

This multiplicity of stimuli would help to consolidate the understanding and sense of authenticity of the experience.

It will also be extremely useful to measure which factors most affect the perception of the credibility and authenticity of the story, also considering the spread of generative AI. Undoubtedly, a convergence between heritage sciences, digital humanities and neurosciences could facilitate the measurement of neurophysiological parameters indicative of well-being and thus the understanding of their activators, both at an individual and collective level. These results could translate into the adoption of increasingly mature strategies in the cultural offer and in heritage valorisation, suitable for all audiences.

Technologies and paradigms change, but the ultimate goal of this research does not change: to nurture understanding, affection and thus a sense of caring for our history, but also to be open to creatively rework our cultural heritage.

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