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DIGITIZATION AND VIRTUAL EXPERIENCE OF MUSEUM COLLECTIONS. THE VIRTUAL TOUR OF THE CIVIC ART GALLERY OF ANCONA

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Abstract

Digital technologies have been shown to be highly effective in many activities related to Cultural Heritage (CH). Among the several impacts discussed in the last few decades, this paper focuses on digitization as a tool for the documentation and the experience of a museum collection. Taking advantage of image-based techniques, a digital replica of the Civic Art Gallery of Ancona was generated. Virtual interactions with the digitized artworks were then enabled and tested in the framework of a Virtual Tour (VT), designed as a solution for the museum to reach a wider public. The evaluation of the VT User eXperience (UX) proved the effectiveness of this tool, highlighting positive connections between the considered dimensions of the VT. The questionnaire scores will inspire further improvement to provide a better educational experience and engage more users.

Keywords

Museum digital collection, Image-based 3D reconstruction, Digital replica, Virtual tour, UX evaluation

1. *Introduction*

Digital technologies have demonstrated their potential in different activities related to Cultural Heritage (CH): from classification to preservation, from communication to restoration, their positive impact has been widely discussed.

This paper focuses on digitization as a tool for the documentation and experience of museums' collections. Indeed, as tested for the Civic Art Gallery of Ancona, the generation of digital replicas opens up several possibilities of virtual interaction, offering to museums different options to make their collections accessible to a wider public.

According to the principles of the London Charter (Brusaporci & Trizio, 2013), the first task was to digitize the museum collection ensuring the scientific rigour of its virtual representation. As it was also recognized by the European Union, the quality of cultural contents conveyed through digital solutions is in fact crucial. Coherently, the strategies for the enhancement of digital transformation promoted for the five-year term 2020-2025 identify the improvement of digital data as one of three main priorities, since it has been proven that the poor quality of the contents and associated metadata strongly affects their visibility and reuse (European Union, 2020).

The second main issue was to structure an appropriate solution for the experience of the generated digital contents, trying to apply the guidelines of the "Triennial Plan for the Digitization and Innovation of Museums" (Direzione generale Musei - MIBACT, 2019). This document provides a national framework for the adoption of digital solutions by Italian museums, that are considered fundamental for the improvement of their management, preservation, exhibition, storytelling, access, and experience.

According to this plan, the main aim of this research was therefore to activate virtual access to a museum collection and to assess its effectiveness. Thus, it was essential to clarify the purpose of the virtual experience, in this case intended as a tool for the museum public broadening, without forgetting that the success of a museum is not related to the number of visits, but to the number of visitors who learned something (Rivière, 1989).

Delving into these topics, Section 2 introduces the research background relating to CH digitization and virtual experiences; Section 3 resumes the research aims; Section 4 presents the case study and the applied methodology; Section 5 shows the obtained results; finally, Section 6 highlights the strengths and weaknesses, also

focusing on future improvements.

2. Background

The pandemic scenario boosted CH digital transition, but critical awareness of digital application is still needed to enable resilient processes for CH experience (Clini & Quattrini, 2021).

In this context, the presented research work started from a literature review of two main topics: the scientific digitization of CH, in particular referring to image-based techniques, and the design and evaluation of CH virtual experience with a focus on Virtual Tour (VT).

2.1 Digital replicas of Cultural Heritage

Digital replicas of CH are one of the most promising innovations for heritage experiences, enabling different interactions with cultural sites and collections (Apollonio, Fantini, Garagnani & Gaiani, 2021). During the last decade, many research works pointed out the effectiveness of image-based 3D reconstruction in different fields of CH: from archaeology (Zampieri, Baldoni, Garagnani, Gaucci & Silani, 2021) to historical architecture (Cabanes & Bonafé, 2021), from the smallest artifact (Clini, Frapiccini, Mengoni, Nespeca & Ruggeri, 2016) to the landscape scale (Demetrescu, d'Annibale, Ferdani & Fanini, 2020), without excluding the underground (Galera-Rodríguez, Angulo-Fornos & Algarín-Comino, 2022) and underwater CH (Bruno, Lagudi, Ritacco, Agrafiotis, Skarlatos, Čejka, Kouřil, Liarokapis, Philpin-Briscoe, Poullis, Mudur & Simon, 2017).

The Structure from Motion (SfM) approach and the Multi View Stereo (MVS) algorithms, which are behind the image-based 3D reconstruction process, can also be exploited to generate gigapixel images. This solution is mainly applied to paintings and makes possible extremely detailed documentation and analyses of this kind of artwork (Cabezos-Bernal, Rodriguez-Navarro & Gil-Piqueras, 2021).

3D reconstructions can also be performed using spherical panoramas (Gottardi & Guerra, 2018). However, even apart from this process, they provide an effective solution for 360° visualization of museum exhibitions (Mah, Yan, Tan, Tan, Tay, Chiam, Wang, Dean & Feng, 2019).

2.2 Cultural Heritage virtual experiences

Since the outbreak of the pandemic, cultural sites have been changing the ways of engaging their public, both onsite (Cirafici, Langella & de Vita, 2022) and remotely (Resta, Dicuonzo, Karacan & Pastore, 2021).

Focusing on VT as a tool to experience museums, its exhibition halls and artworks on display, *Google Arts & Culture* (formerly *Google Art Project*) provides Virtual Gallery Tours, in which users can virtually "walk-through" the galleries of the cultural partners involved in the project (Proctor, 2011). Bonacini (2015) examined the importance of this initiative, highlighting the need for additional contents to enrich the provided experience. As discussed in (Mah et al., 2019), where a VT for the preservation of tangible and intangible heritage is enriched with high-resolution images, and video interviews with the personnel involved in the management of heritage and historical archives. Resta et al. (2021) evaluated the archaeological museum VT of Troya Müzesi in Çanakkale, Turkey. This experience was generated in Matterport, a cloud platform that allows VTs creation with a standard online interface that includes hotspots on the ground and tags on the objects. So, the visit experience is enriched by pop-up windows that provide detailed descriptions of the artifacts on display and web links to external sources. Bagnolo et al. (2021) explored the digitization of CH also focusing on educational purposes, outlining an approach slightly different from the simple VT, intended as mere navigation within digitally reproduced physical spaces.

Regarding gigapixel images experience, *Google Arts & Culture* offers gigapixel images of the masterpieces from different collections on its platform. For example, the gigapixel image of the Starry Night by Vincent Van Gogh (Google, 2020) allows the user to take a closer look at the painting, explore its finest details, and learn more about it through the textual insights and related videos from YouTube. By clicking the Street View button, it is possible to explore the exhibition hall of the museum, but no interaction with this or other paintings are provided while exploring the spherical panoramas. Remaining within the field of gigapixel images, the Operation Night Watch, carried out by the Rijks Museum, demonstrates the close connection between conservation, restoration, and enhancement of artworks

experience. As part of this project, Experience the Night Watch allows users to navigate the gigapixel image of Rembrandt van Rijn's Night Watch. After a short intro, different hotspots appear on the painting in relation to the zoom level. The whole experience is structured within the gigapixel image, and it is supported by video animation and audios. Both general audience and children's tours are available.

Having so many digital solutions, a crucial task is to adapt the CH virtual experience to the expected objective. Network of European Museum Organizations - NEMO (2021) highlighted that one museum out of three developed a VT in response to the pandemic. However, more awareness about their effectiveness is needed to provide capable experiences of engaging visitors, stimulating a learning process, and piquing their interest in physically visiting museums. In this regard, Resta and Karacan (2020) evaluate the relationship between interactive technology and visitor experience, focusing on how digital storytelling enhances the visit of a virtual exhibition, using a questionnaire to measure participant interaction, personalization, and engagement. Taking the VT of the Exhibition of Architecture of the Forbidden City as a case study, Li et al. (2022) establishes a heuristic evaluation scale based on four dimensions: authenticity, interactivity, navigation, and learning, to highlight strengths and weaknesses of this kind of virtual experience.

3. Research aims

Using the case study of a museum characterized by a great variety of artworks - from painting to statues, from medieval to contemporary art - this study aims to offer a methodological framework for the digitization of museum collections, for their virtual experience and its evaluation. This research intends to investigate VT as a container to generate an effective storytelling of the artworks on display. In this regard, high-resolution spherical panoramas, gigapixel images, and 3D models, along with texts, audios, and videos provided by art experts are integrated into the VT to generate an experience that enables users to virtually step into the world of the artworks.

Since education is essential for museums (ICOM, 2022), previous studies have already evaluated the learning dimension in CH virtual experiences. In addition, this paper includes the economical value of digital technologies as another crucial aspect, by investigating the effects of VT on extending audience reach (Bakhshi & Throsby, 2009). Therefore, another research aim was to provide a questionnaire to evaluate these two main aspects, along with the most recognized virtual UX dimensions to understand their connections.

4. Material and methods

4.1 The Civic Art Gallery of Ancona

The Civic Art Gallery of Ancona was established in 1884. At that time the painter Francesco Podesti donated a series of his preparatory cartoons and sketches. Over the years many ancient artworks from churches and municipal funds have been gathered, and in 1973, Palazzo Bosdari became home to the collection. The building, and Palazzo Bonomini was annexed in 2012.

The main façade of the building is opened by three orders of windows and a central portal with heavy pediments. The building is structured around the courtyard, a portico with three bays with round arches on brick pillars, completed by a stone balustrade, enriched by two wells and two elegant stone twin portals leading to the rooms on the ground floor. A staircase leads to the monumental rooms of the first floor, among which the main hall, which develops in height also occupying the mezzanine. Its wooden ceiling divided into panels is characterized by the presence of the heraldic lily, coat of arms of the family that owned the building. On the walls, below the ceiling there is a frieze in fresco with allegorical figures, architectural elements, and medallions.

The collection of the Civic Art Gallery of Ancona is characterized by a huge variety of artworks. Paintings by Francesco Podesti, after whom the gallery is named, are displayed alongside the modern works by the greatest artists of the Italian 20th century. Medieval and Renaissance masterpieces by Carlo Crivelli, Titian, Lorenzo Lotto and Sebastiano del Piombo are also exhibited among contemporary works, representing the perpetual dialogue between past and present.

4.2 The digitization of halls and artworks

The first step of the digital replica generation process was to assess the most suitable techniques

for the documentation of the exhibition halls and displayed artworks. Based on the subjects, three different workflows were set: capturing and processing of spherical panoramas of the halls, a photogrammetry-based workflow for the 3D reconstruction of statues, and gigapixel photography for the paintings.

As far as 360° images are concerned, 18 shots were captured for each of them, using a Sony α9 full-frame digital camera, mounting an f/4 12-24 mm lens, on a Nodal Ninja panoramic head. As it is well known, the sensor dimensions and the focal length determine the number of single images needed to stitch the spherical panorama and its final resolution. Having a full-frame sensor, and setting the focal length at 15 mm, the image capturing phase was designed to generate 16.384 x 8.192 pixels equirectangular images. The goal was to represent artworks with a proper level of detail. So, particular attention was paid to the choice of the shooting points, capturing all the exhibition halls. Due to issues related to their lighting system and dimensions, more than one shooting point was needed for almost all the exhibition halls. For each set of images an additional shoot was taken by positioning a grey card in the scene.

Images related to a single panorama were simultaneously pre-processed using the Adobe Photoshop plug-in CameraRaw for the white balance correction using the grey-card image, and contrast enhancement. Finally, using the software PTGui, the shots were automatically stitched into a single spherical panorama, after manually placing control points to straighten vertical lines for a proper visualization. Fig. 1 shows a 360° image of the Altarpieces Hall and enlargements that highlight a closer look at the paintings. Despite precautions, the representation of some areas is affected by the lighting condition.

Regarding the 3D reconstruction of the statues, the process was carried out according to the following steps: data capturing, image pre-processing, automatic 3D reconstruction, 3D meshes post-processing, retopology, normal texture baking, and diffuse colour mapping (Fig. 2).

The data capturing phase was carried out using a Sony α9 full-frame digital camera, mounting a f/2.8 24-70 mm lens. The lighting system consisted of two led panels (480 led, 26 x 26.5 x 5 cm), emitting continuous spectrum light at a Correlated Color Temperature of 4000°K, a brightness of 3360 lux at 1 m and a Color Rendering Index ≥96%. To ensure a uniform and diffuse illumination, the two panels were both equipped with a diffusion filter. Movable objects were put inside a white translucent softbox on a

Fig. 1: Spherical panorama of the Altarpieces Hall, Civic Art Gallery, Ancona.

rotating support, a turntable mounted on a Syrp Genie Mini connected to the camera to automate image acquisition. For each statue, an additional image was taken by positioning an X-Rite ColorChecker Classic in the scene.

First of all, each image with the colour chart was processed in ColorChecker Camera Calibration, a software that generates a colour profile automatically recognising the represented target. Each colour profile was then applied to the different sets of images using Adobe CameraRaw, correcting, and enhancing white balance and contrast among others. The automatic 3D reconstruction was carried out using Agisoft Metashape. Thanks to this software is it possible to perform images alignment, camera position optimization and scaling, dense cloud processing and filtering, and finally 3D mesh reconstruction.

The photogrammetric output was then post-processed, enhancing the previous automatic result. The 3D mesh was cleaned and edited in Meshlab, removing topological errors and unwanted parts, filling holes and smoothing surfaces. Using retopology filters, a low-poly version of each model was obtained. The UV unwrapping and the normal baking from high-poly to low-poly version were performed in Blender.

In the end, 3D models were imported into Metashape for diffuse colour mapping.

As for the previous data capturing, gigapixel photography was carried out using a Sony α9 full-frame digital camera, mounting in this case an f/2.8 90 mm macro lens. The adopted acquisition technique was parallel-multi-viewpoint capturing. The camera was mounted on a Syrp Magic Carpet Pro, a slider that provided a solution adaptable to paintings of different size thanks to its modular structure. The horizontal movement of the camera was then automatically performed using the slider. Its remote control made it possible to set up the number of shots for each row and their timing, ensuring an adequate interval related to the exposure time. The vertical movement was manually performed, raising the stands anchored to the slider after capturing each row. The same led panels used for the 3D reconstruction of statues were also used for gigapixel photography. In this case, they were mounted on the sides of the camera, fixed to a steel bar connected to the slider. The lights were oriented according to the field of view to avoid specular reflections on the canvas. Regarding camera settings, ISO value was set to 100, shutter speed to 8", and the diaphragm aperture to f/16, ensuring an adequate depth of field. Also for this acquisition technique, a X-Rite ColorChecker Classic was used to generate colour profiles. Captured images for each painting acquisition were processed using the software Agisoft Metashape. The same workflow described for 3D models was applied. Finally, orthoimages of the paintings were processed by projecting the single shots on the obtained geometry (Fig. 3). Due to the specs of the lens and of the sensor, the camera was placed no more than 56 cm from the painting, so the minimum GSD granted by the

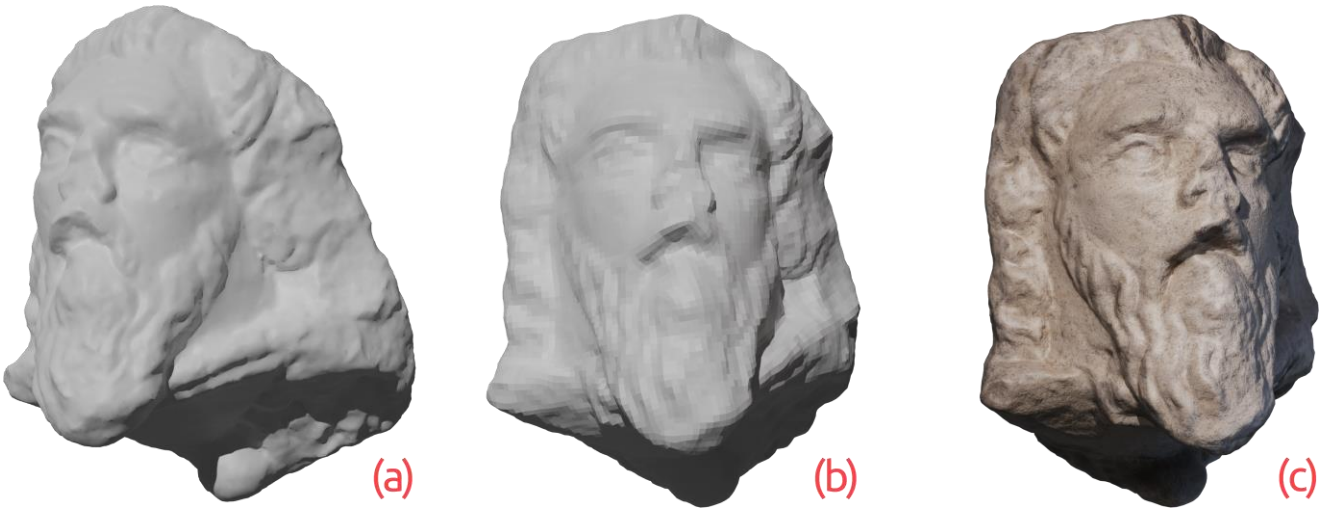

Fig. 2: Man's head, Unknown Tuscan artist, XII century., Civic Art Gallery, Ancona.
Image-based 3D reconstruction (a); low-poly model (b); baked and textured final output (c).

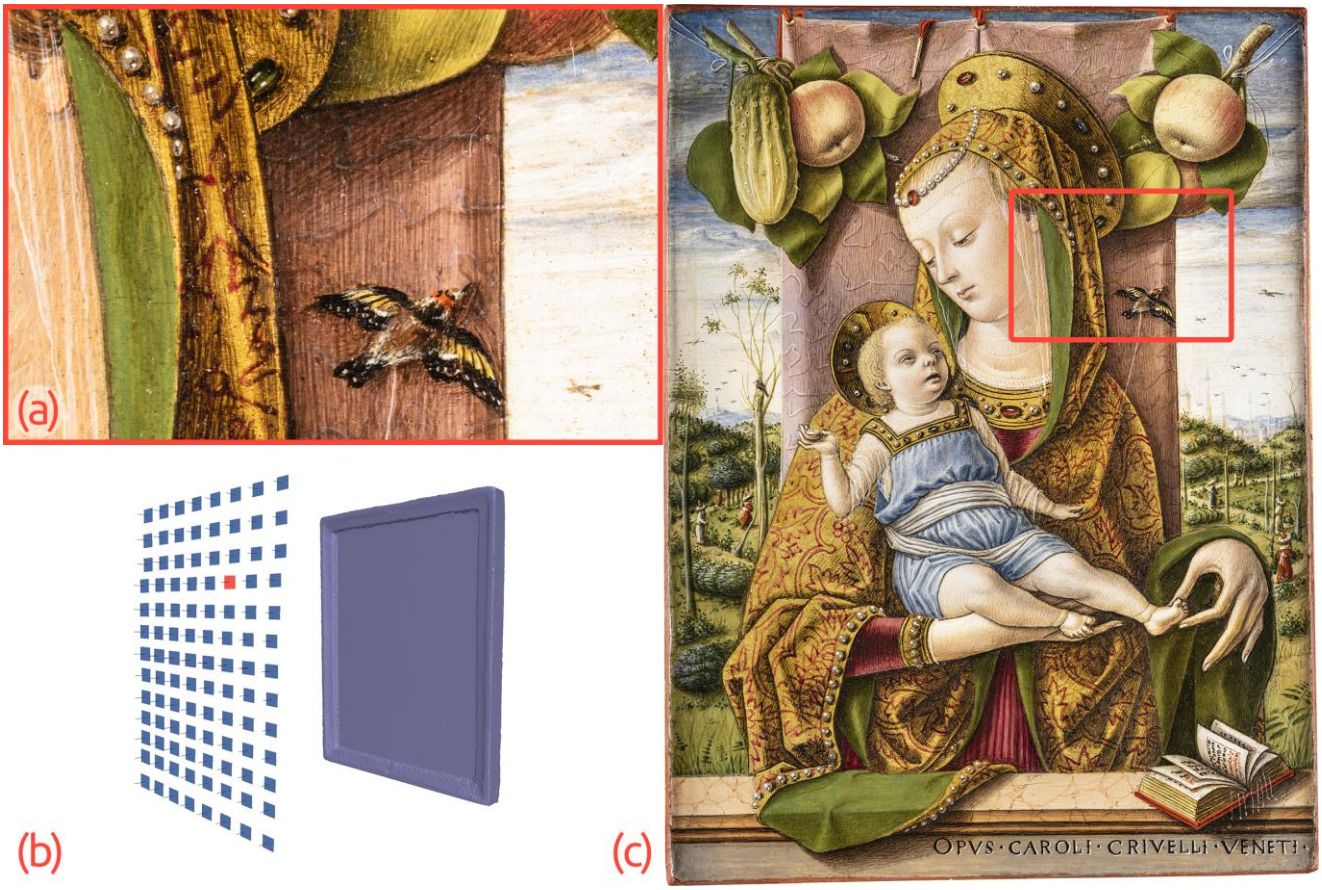

Fig. 3: Madonna col Bambino, Carlo Crivelli, Civic Art Gallery, Ancona.
Single shot (a); images aligned to be reprojected on the 3D model (b); gigapixel image (c).

acquisition was 0,024 mm, therefore a resolution of 1050 ppi in full-scale reproduction.

4.3 The Virtual Tour of the Gallery

The VT of the Civic Art Gallery of Ancona was generated using the commercial software Pano2VR. Consequently, it was possible to customize the User Interface (UI) appearance and all the interactions, which is crucial for structuring an adequate UX. The aim was to provide the users with interactive digital storytelling offering two different digital experiences: a completely free one, mostly like VTs by Google Arts & Culture, and a guided one, related to specific topics relevant to this collection. Both experiences are characterized by active interaction processes that allow users to change their itinerary, chose the desired artwork for in-depth observation, and receive advice about the next artwork to experience. In particular, the implementation of thematic itineraries was aimed at introducing different storylines of the virtual experience. VTs usually lack in narrative layers and present museums without permitting a guided tour. The provided solution is therefore functional to overcome this lack, by offering more topical and less historical stories that would deepen visitors' interest in specific artworks and enhance their overall experience of the exhibition.

Regarding the UI, the default one provided by Pano2VR was modified by adding customized buttons. A "Map" button improves the VT navigation, activating a map to move through the exhibition halls, and to visit different floors of the Art Gallery. Being particularly relevant both from an artistic and a historical perspective, a "Building" button activates an image-gallery accompanied by a text that describes the architecture and main events of Palazzo Bosdari. This is paired with the "Collection" button that provides general information about the displayed artworks. The "Museum itineraries" button can be used to select a specific topic and to start exploring the related thematic guided tour. Other five buttons complete the UI: "Help us with your opinion", which leads to

the VT evaluation questionnaire, allowing to collect more data for further analysis; "Reach us", for information on how to reach the Civic Art Gallery; "Share", to post the VT on social media; "Help", to get more information about the VT functioning; and "Credits". If the used device supports the VR mode, an "Enter VR" button will also appear on the controller bar, to offer an immersive experience (Fig. 4).

Upon entering the Civic Art Gallery, a text and an audio provide an explanation of the main VT features. Users are then allowed to choose whether to freely explore the exhibition or to follow a set itinerary. In the first case, it is possible to go through the exhibition halls by clicking on the hotspots placed in the 360° images. By hovering the mouse over different artworks, a label shows the title, author, and date. By clicking on an artwork, a popup appears and displays the related data from the Cultural Heritage Catalogue of the Marche region. For selected artworks, more information about the representation and the author is also provided and it is possible to recall a 3D model and/or a gigapixel image. As far as 3D digital replicas are concerned, they are hosted on the *Sketchfab* platform and embedded within the VT. This makes it possible to explore models, and to read the textual information by clicking on the hotspots. Unlike 3D models, gigapixels are uploaded directly in the VT. So, it was possible to enrich their visualization with more interactions and multimedia contents, combining the possibility to observe relevant details, not visible to the naked eye, together with text, audios, images, and videos which reveal their hidden meanings. Indeed, the use of highly detailed digital replicas, above all gigapixels, was intended to allow visitors to more closely look at the artworks, and to immerse in their virtual representations up to the finest details. If users select the guided experience, the point of view is automatically set to the first related artwork. A pop-up introduces it in relation to the topic of the selected itinerary; the users are then invited to click on it to discover more contents. In this way, they activate a popup that recalls information, insights, 3D model and/or a gigapixel image of the artwork. Closing this popup, paintings become a passage to the next exhibition hall, that users can immediately go through to reach the subsequent related artwork (Fig. 5).

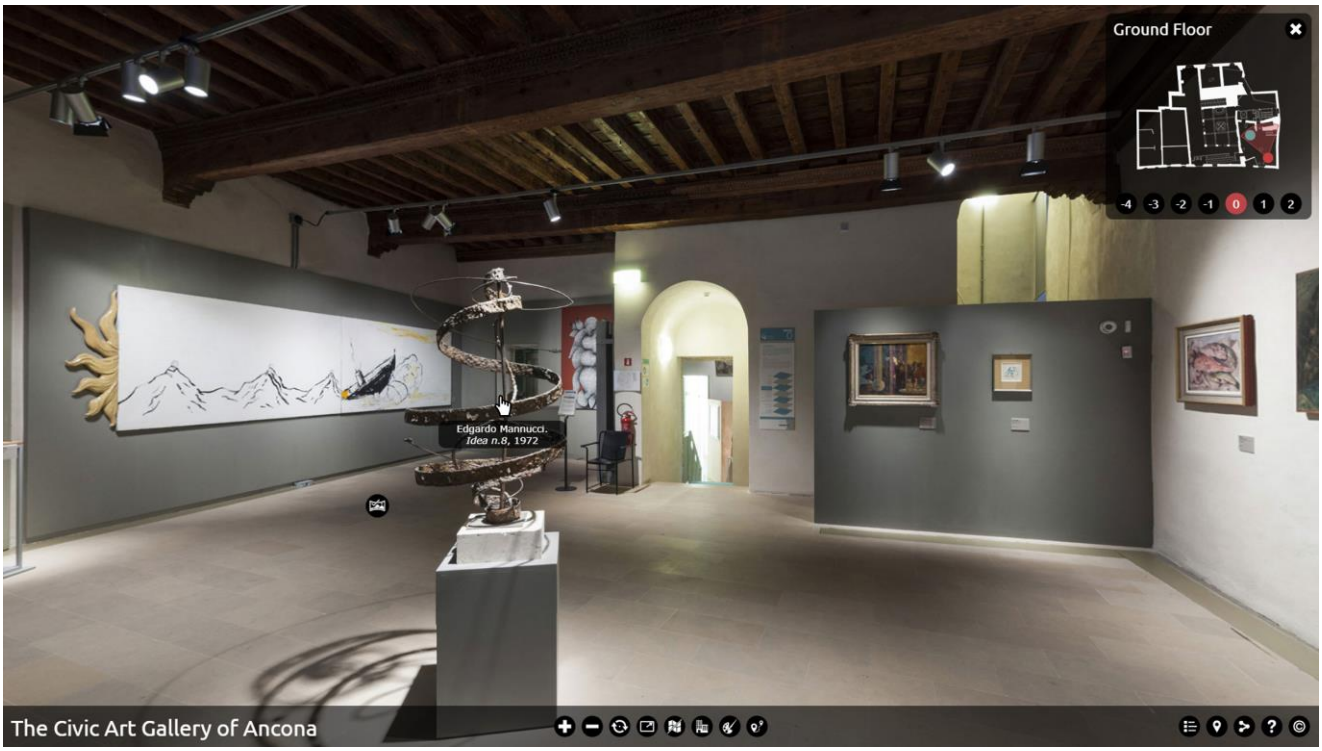

Fig. 4: Contemporary Art exhibition hall, Civic Art Gallery, Ancona. Virtual Tour User Interface.

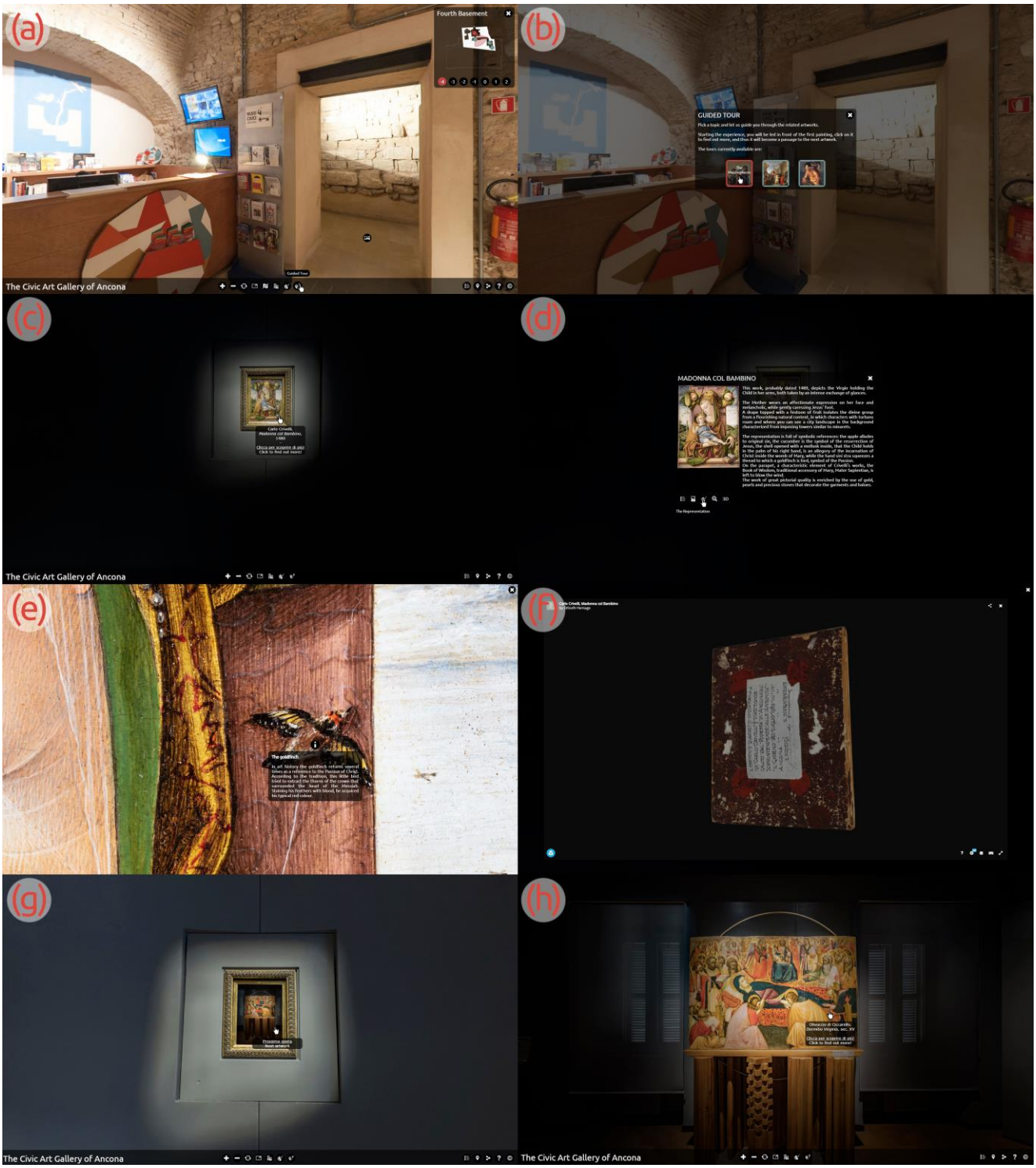

Fig. 5: VT guided experience: selection button (a); itinerary selection (b); first exhibition hall (c); artwork insights interface (d); gigapixel visualization (e); 3D model visualization (f); hotspot to the next exhibition hall (g); next exhibition hall (c).

The described VT was then evaluated with a questionnaire based on 11 factors referred to 5 dimensions: authenticity, interaction, navigation, learning, and audience broadening. The questionnaire was divided into two parts: the first one according to the 11 factors, with a total of 15 items, each of them set to *strongly disagree*, *disagree*, *general*, *agree* and *strongly agree* on a five-level Likert scale (Tab. 1); the second one was a demographic variable questionnaire and

gathered information including age, gender, educational background, and previous VT experience using a single choice format.

In addition to the questionnaire, a final interview was carried out, with six pairs of questions focusing on the overall feeling about the experience and the five dimensions on the scale (Tab. 2). The test procedure involved the following steps: at first, the test participants were asked to freely experience the VT, then to follow a pre-set museum itinerary, exploring the related artworks and their contents. In particular, they were invited to follow "The Masterpieces of the Civic Art Gallery of Ancona" itinerary, without being forced to conclude it. On the second stage, the subjects filled the questionnaire. Finally, interviews were carried out. The test for each participant lasted about 15-20 minutes.

Tab. 1: Evaluation scale for museums virtual tour aimed at audience broadening

Dimension	Definition	Factor	Definition	Item
A. Authenticity	How close is the virtual reality to the physical one.	A.1 Environmental authenticity	The virtual environment is as close as possible to the real world.	Q.1 The exhibition hall representation was very realistic.
				Q.2 The artifact representation was very realistic.
		A.2 Experience authenticity	The virtual experience is as close as possible to a real visit.	Q.3 I felt like I was wandering in a real museum.
B. Interaction	How the virtual reality reacts to user action.	B.1 Environmental reaction	Virtual environment reaction meets user expectations.	Q.4 Interaction with the exhibition halls was natural.
				Q.5 Interaction with objects was natural.
		B.2 Ease of interaction	Ease of interaction within the virtual experience.	Q.6 It was easy to interact with the virtual environment.
C. Navigation	Identify location and direction within the virtual environment.	C.1 Clarity of location	Users know their location.	Q.7 I always knew where I was.
				Q.8 I managed to locate myself when I felt lost.
		C.2 Clarity of direction	Users know the visit direction.	Q.9 I always knew the visit direction.
D. Learning	Get information experiencing the virtual environment.	D.1 Information abundance	The experience provides enough information.	Q.10 The VT provides enough information.
		D.2 Information quality	The provided information quality is good.	Q.11 Information was clearly communicated.
				Q.12 Information was interesting.
E. Audience broadening	Capturing a wider public, among traditional museum visitors.	E.1 Connectivity to other potential users.	Users are willing to share their experience with others.	Q.13 I will recommend this experience.
		E.2 Connectivity to other virtual experiences.	Users are willing to experience other virtual tours.	Q.14 I will look for more virtual tours.
		E.3 Connectivity to the physical museum.	Users are willing to physically visit the museum.	Q.15 I will visit the Civic Art Gallery of Ancona.

Tab. 2: The interview questions related to the overall feeling and the five dimensions investigated by the questionnaire.

Dimension	Questions
The overall feeling	1) How did you feel about the experience?
	2) Which were the main problems you encountered?
Authenticity	3) Did you feel like visiting a real museum exhibition?
	4) Did you feel immerse in the virtual environment?
Interaction	5) How did you feel interacting with the virtual environment?
	6) Did the virtual environment react as you were expecting?
Navigation	7) Did you have trouble following the visit direction?
	8) Did you ever feel lost?
Learning	9) Do you think you can learn anything from this experience?
	10) Did you find the experience interesting?
Audience broadening	11) Will you recommend museum virtual tour experience to other people?
	12) Will you recommend visiting the Civic Art Gallery of Ancona to other people?

5. *Results and discussion*

The output of the research work is an interactive VT of the Civic Art Gallery of Ancona, offering a new experience of its collection thanks to digital replicas, whose effectiveness was evaluated using questionnaires and interviews.

A total of 40 people participated, respondents included 22 females and 18 males, with most respondents aged 18-30 (55%). Most of them had a master degree (52,4%) and were experiencing an online museum virtual tour for the first time (70%). *Agree* and *Strongly agree* accounted for more than 50% of all responses, demonstrating that most subjects were satisfied with the experience.

The reliability of the test was measured with the Cronbach's alpha model across the five dimensions. Results in Tab.3 proved their reliability.

Tab. 3: Dimensions reliability

Dimension	Cronbach's α
Authenticity	0,780
Interaction	0,704
Navigation	0,759
Learning	0,770
Audience broadening	0,760

Fig. 6 shows the questionnaire results. It is immediately evident that the authenticity dimension is the most satisfying, whereas the interaction one had the lowest performances. This result confirms that VTs provide an experience not very rich in interaction, but efficient in terms of authenticity. Although 360° images realistically represent the real environment, as already pointed out in other studies, the interaction mode may sometimes disorient users.

A more in-depth discussion can be structured by analysing in detail the different scores of the 5 dimensions considered in the evaluation tests.

As already stated in the result section, the Authenticity dimension got the best rating. In particular, the scores of Q1 and Q2 prove the perceived authenticity of the digital replica of both exhibition halls and artworks. Interactivity obtained the worst scores, with Q4 far below average. As pointed out by the answers to interview question number 6, the change in perspective direction from a spherical panorama to another is a crucial aspect. Therefore, the pre-set view of the 360° images is not always consistent with users' expectations. This issue can be addressed by covering the halls with a larger number of 360° images and maintaining the same viewing direction while moving to the next spherical panorama, as standardized by *Google Maps Street View*, and proposed in VTs by *Google Arts & Culture*. However, this option was discarded in the VT design phase for two reasons: increasing the number of 360° images entails more time for data capturing and processing. It also slows down the virtual experience, increasing the number of clicks to move from an exhibition hall to the other. Moreover, keeping the viewing direction of the previous panorama certainly guarantees the loyalty of perspective, but sometimes can lead to undesirable viewing perspectives. In a physical environment visitors' movement is continuous and their perspective changes coherently. Due to

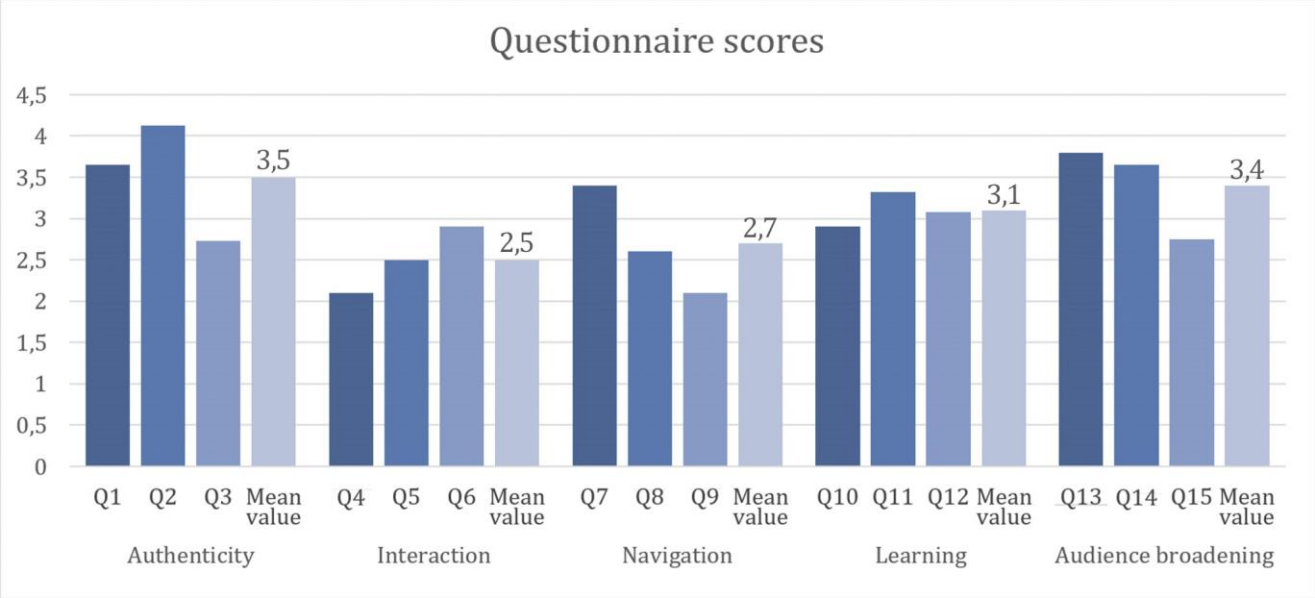

Fig. 6: Scores and mean value of the three items related to each considered dimension.

its technical limitations, a VT based on 360° images does not permit this kind of behaviour. For this reason, it was decided to automatically set the viewing direction when a panorama is changed. The 360° images' default view was defined, following the museum set-up that is already designed to determine privileged perspectives within the exhibition. The *Navigation* scores were slightly above average. Q7 and Q8 obtained the best results, as the users were able to easily locate their position on the map. Regarding Q9, its low score is affected by the previously mentioned limits of 360° images navigation mode. A museum itinerary is usually represented as a one-direction path, along which visitors move towards artworks. The provided VT shows the exhibition halls with 360° image mostly from the central part of the rooms, which may not always help users to follow the museum path.

The Learning results confirm that the VT can provide information in a clear and interesting manner to users. Although questionnaire scores suggest that the VT provides enough information, on the other hand, interviews highlighted the need for a more balanced distribution of the insights. In particular, answers to interview question number 9 indicate that 3D models and gigapixel images must be more uniformly distributed.

Finally, the Audience broadening results are slightly under the Authenticity ones, demonstrating the success of the VT as a tool for audience reach extending. It is significant that users are not only interested in visiting the art gallery in person, but they would also look for more CH VTs.

Since providing a learning experience to users and broadening audiences of the museum were the two main aims of the VT, the relations with the other three considered dimensions were also evaluated. Regression analysis results show the positive correlation between them, and that the most significant relation seems to be the one between a good learning experience and the audience broadening dimension (Tab. 4).

Tab. 4: Learning and Audience broadening correlations with other dimensions and between them.

Relation	Correlation coefficient	R square
Authenticity- Learning	0,758	0,574
Interaction- Learning	0,652	0,425
Navigation- Learning	0,570	0,325
Authenticity- Audience broadening	0,752	0,566
Interaction- Audience broadening	0,635	0,403
Navigation- Audience broadening	0,571	0,326
Learning- Audience broadening	0,815	0,664

6. *Conclusions*

This work provided a solution to improve the accessibility of museum collections, thus ensuring

the scientific rigor of digital replica. The evaluation test demonstrated the effectiveness of VT as a tool for the learning experience and audience broadening. The obtained results also showed their positive relations with the perceived authenticity of the virtual environment, the possibilities of interaction, and the navigation mode. The conclusions of this study are summarized as follows:

1. Spherical panorama, 3D models, and gigapixel images provide a realistic perception of the virtual environment and particularly of the displayed objects, thus ensuring a good experience with reference to the Authenticity dimension.
2. If virtual interaction is not optimal compared to the experience in person, because the point of view within spherical panorama is fixed i.e., users are only allowed to zoom-in to get closer to the artworks.
3. Navigation within spherical panoramas needs improvements to help users to better understand the exhibition itinerary.
4. The information provided by the VT is effective, but the learning experience could be incomplete since digital replicas and additional contents are not provided for each artwork.
5. After testing the VT, users are interested in visiting exhibitions in person and even more in experiencing other VTs.

The analysis of the relationship between the five dimensions considered demonstrated that Authenticity, Interaction, and Navigation have a positive relation with Learning and Audience broadening. It also highlighted that users who had a good educational experience are the ones who most likely recommend the VT and are the most interested in visiting the Art Gallery in person.

Looking beyond the aims of this study, future works will consider involving museum staff in the process of digitalization. Indeed, the engagement of museum professionals is crucial to ensure even a greater connection between a cultural site and its digital replica, and to secure the sustainability of the whole process.

Moreover, VT could be compared to other virtual solutions, evaluating their impact on visitors, and how different digital tools can be combined to further amplify CH experiences both online and onsite.

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REFERENCES

Apollonio, F.I., Fantini, F., Garagnani, S. & Gaiani, M. (2021). A Photogrammetry-Based Workflow for the Accurate 3D Construction and Visualization of Museums Assets. *Remote Sens.*, 13 (486), 1-39. Retrieved from https://doi.org/10.3390/rs13030486

Bakhshi, H. & Throsby, D. (2009), *Innovation in Arts and Cultural Organisations*, Hamburg, Germany: Nesta.

Bonacini, E. (2015). A pilot project with Google Indoor Street View: a 360° tour of "Paolo Orsi" Museum (Syracuse, Italy). *SCIRES-IT - SCIentific RESearch and Information Technology*, 5(2), 151-168. Retrieved from http://dx.doi.org/10.2423/i22394303v5n2p151

Bruno, F., Lagudi, A., Ritacco, G., Agrafiotis, P., Skarlatos, D., Čejka, J., Kouřil, P., Liarokapis, F., Philpin-Briscoe, O., Poullis, C., Mudur, S., & Simon, B. (2017). Development and integration of digital technologies addressed to raise awareness and access to European underwater cultural heritage. An overview of the H2020 i-MARECULTURE project. In *OCEANS 2017* (pp. 1-10). Aberdeen, Scotland: IEEE. Retrieved from http://dx.doi.org/10.1109/OCEANSE.2017.8084984

Brusaporci, S. & Trizio, I. (2013). La "Carta di Londra" e il Patrimonio Architettonico: riflessioni circa una possibile implementazione. *SCIRES-IT - SCIentific RESearch and Information Technology*, 3(2), 55-68. Retrieved from http://dx.doi.org/10.2423/i22394303v3n2p55

Cabanes, J. L., & Bonafé, C. (2021). Computer Vision algorithms performance in Architectural Heritage Multi-Image based projects. General overview and operative evaluation: the North Tower of Buñol´s Castle (Spain). *SCIRES-IT - SCIentific RESearch and Information Technology*, 11(2), 125-138. Retrieved from http://dx.doi.org/10.2423/i22394303v11n2p125

Cabezos-Bernal, P. M., Rodriguez-Navarro, P., & Gil-Piqueras, T. (2021). Documenting Paintings with Gigapixel Photography. *Journal of Imaging*, 7 (156), 1-20. Retrieved from https://doi.org/10.3390/jimaging7080156

Cirafici, A., Langella, C., de Vita, O. (2022). AURA_ a media device for new narration spaces in museum contexts. *SCIRES-IT - SCIentific RESearch and Information Technology*, 12(1), 133-150. Retrieved from http://dx.doi.org/10.2423/i22394303v12n1p133

Clini, P., & Quattrini, R. (2021). Editorial. Digital Cultural Heritage, arts reproduction and museum systems. Languages and techniques in a Covid and post-covid scenario for new forms of heritage against the silence of a fragile culture. *SCIRES-IT - SCIentific RESearch and Information Technology*, 11(1), 1-10. Retrieved from http://dx.doi.org/10.2423/i22394303v11n1p1

Clini, P., Frapiccini, N., Mengoni, M., Nespeca, R., Ruggeri, L. (2016). SFM technique and focus stacking for digital documentation of archaeological artifacts. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLI (B5), 229-236. Retrieved from http://dx.doi.org/10.5194/isprsarchives-xli-b5-229-2016

Direzione generale Musei - MIBACT (2019). Piano Triennale per la Digitalizzazione e l'Innovazione dei Musei. Retrieved from http://musei.beniculturali.it/wp-content/uploads/2019/08/Piano-Triennale-per-la-Digitalizzazione-e-l'Innovazione-dei-Musei.pdf

Demetrescu, E., d'Annibale, E., Ferdani, D., & Fanini, B. (2020). Digital replica of cultural landscapes: An experimental reality-based workflow to create realistic, interactive open world experiences. *Journal of Cultural Heritage*, 41, 125-141. Retrieved from https://doi.org/10.1016/j.culher.2019.07.018

European Union (2020). Europeana Strategy 2020-2025. Empowering Digital Change. *Publications Office of the European Union*. Retrieved from https://doi.org/10.2759/524581

Galera-Rodríguez, A., Angulo-Fornos, R., & Algarín-Comino, M. (2022). Survey and 3D modelling of underground heritage spaces with complex geometry: surface optimisation for association with HBIM methodology. *SCIRES-IT - SCIentific RESearch and Information Technology*, 12(1), 177-190. Retrieved from http://dx.doi.org/10.2423/i22394303v12n1p177

Google Arts & Culture (2020). The Starry Night by Vincent Van Gogh. Retrieved from https://artsandculture.google.com/asset/the-starry-night-vincent-van-gogh/bgEuwDxel93-Pg

Gottardi, C. & Guerra, F. (2018). Spherical images for Cultural Heritage: survey and documentation with the Nikon KM360. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII (2), 385-390. Retrieved from https://doi.org/10.5194/isprs-archives-XLII-2-385-2018

ICOM (2022). ICOM approves a new museum definition. Retrieved from https://icom.museum/en/news/icom-approves-a-new-museum-definition/

Li, J., Nie, J. W. & Jing, Y. (2022). Evaluation of virtual tour in an online museum: Exhibition of Architecture of the Forbidden City, *PLos ONE*, 27(1), 1-17. Retrieved from https://doi.org/10.1371/journal.pone.0261607

Mah, O. B. P., Yan, Y., Tan, J. S. Y., Tan, Y., Tay, G. Q. Y., Chiam, D. J., Wang, Y., Dean, K. & Feng, C. (2019). Generating a virtual tour for the preservation of the (in)tangible cultural heritage of Tampines Chinese Temple in Singapore. *Journal of Cultural Heritage*, 39, 202-211. Retrieved from https://doi.org/10.1016/j.culher.2019.04.004

Network of European Museum Organisations - NEMO. (2021). Follow-up survey on the impact of the COVID-19 pandemic on museums in Europe. Final Report. Retrieved from https://www.nemo.org/fileadmin/Dateien/public/NEMO_documents/NEMO_COVID19_FollowUpReport_11.1.2021.pdf

Proctor, N. (2011). The Google Art Project: A new generation of museums on the web? The Museum Journal, 54(2), 215-221. Retrieved from https://doi.org/10.1111/j.2151-6952.2011.00083.x

Resta, G. and Karacan, E. (2020). Virtual exhibition and visitor experience: How digital storytelling enhances online exhibition spaces. In Y. Aksoy, E. Duyan (Eds.), *Experience in Architecture. Space, perception, function* (pp. 135-154). Istanbul, Turkey: DAKAM.

Resta, G., Dicuonzo, F., Karacan, E., Pastore, D. (2021). The impact of virtual tours on museum exhibitions after the onset of Covid-19 restrictions: visitor engagement and long term perspectives. *SCIRES-IT - SCIentific RESearch and Information Technology*, 11(1), 151-166. Retrieved from http://dx.doi.org/10.2423/i22394303v11n1p151

Rijks Museum. Operation Night Watch. Retrieved from https://www.rijksmuseum.nl/en/whats-on/exhibitions/operation-night-watch

Rijks Museum. Operation Night Watch. Retrieved from https://www.beleefdenachtwacht.nl/en

Rivière, G. H. (1989), *La muséologie selon Georges Henri Rivière*, Paris, France: Dunod.

Zampieri, E., Baldoni, V., Garagnani, S., Gaucci, A., & Silani, M. (2021). The art of pottery from the Picenum area: digital reconstruction and color replication of vases found in the Davanzali necropolis in Numana. *SCIRES-IT - SCIentific RESearch and Information Technology*, 11(2), 1-8. Retrieved from http://dx.doi.org/10.2423/i22394303v11n2p1