

# Project CHANGES - Spoke 4

D4 – Meta-analysis of the technological context – v1.0

31 August 2023

## Deliverable information

Work package	WP3
Deliverable leader	CNR
Authors(s)	<p>Pescarin, Sofia (<a href="https://orcid.org/0000-0002-9529-7083">https://orcid.org/0000-0002-9529-7083</a>): Istituto di Scienze del Patrimonio Culturale, Consiglio Nazionale delle Ricerche</p> <p>Bertini, Marco (<a href="https://orcid.org/0000-0002-1364-218X">https://orcid.org/0000-0002-1364-218X</a>): Dipartimento di Ingegneria dell'Informazione, Università di Firenze</p> <p>Bevilacqua, Luca: Engineering</p> <p>Damiano, Rossana (<a href="https://orcid.org/0000-0001-9866-2843">https://orcid.org/0000-0001-9866-2843</a>): Dipartimento di Informatica, Università di Torino</p> <p>Fanini, Bruno (<a href="https://orcid.org/0000-0003-4058-877X">https://orcid.org/0000-0003-4058-877X</a>): Istituto di Scienze del Patrimonio Culturale, Consiglio Nazionale delle Ricerche</p> <p>Furferi, Rocco (<a href="https://orcid.org/0000-0001-6771-5981">https://orcid.org/0000-0001-6771-5981</a>): Dipartimento di Ingegneria Industriale, Università di Firenze</p> <p>Gentile, Manuel (<a href="https://orcid.org/0000-0001-6288-0830">https://orcid.org/0000-0001-6288-0830</a>): Istituto di Tecnologie Didattiche, Consiglio Nazionale delle Ricerche</p> <p>Montanari, Roberto: Centro di Ricerca Scienza Nuova, Università Suor Orsola Benincasa</p> <p>Thun-Hohenstein, Ursula (<a href="https://orcid.org/0000-0003-2835-3679">https://orcid.org/0000-0003-2835-3679</a>): Dipartimento di Studi Umanistici, Università di Ferrara</p>
Deliverable status	Final
Deliverable version	v1.0
Date	31 August 2023

## Deliverable history

Version	Release date	Summary of changes	Institution(s)
v0.8	09 June 2023	First draft	CNR
v0.9	29 August 2023	Second draft	CNR, UNISOB, UNIFI, UNITO, Engineering
v1.0	31 August 2023	Final and Revised version using the new deliverable template and including additional information and links	CNR



## Spoke information

### Scientific coordinator

Silvio Peroni – [silvio.peroni@unibo.it](mailto:silvio.peroni@unibo.it) – <https://orcid.org/0000-0003-0530-4305>

Dipartimento di Filologia Classica e Italianistica

Alma Mater Studiorum – Università di Bologna

Via Zamboni 32, 40126 Bologna (BO), Italia

### Scientific co-coordinator

Gianluca Genovese – [gianluca.genovese@unisob.na.it](mailto:gianluca.genovese@unisob.na.it) – <https://orcid.org/0000-0002-1064-2061>

Dipartimento di Scienze Umanistiche

Università degli Studi Suor Orsola Benincasa

Via Suor Orsola 10, 80135 Napoli (NA), Italia

## Spoke partners

No	Name	Acronym	Role
1	Alma Mater Studiorum – Università di Bologna	UNIBO	Spoke leader
2	Università degli Studi Suor Orsola Benincasa	UNISOB	Spoke co-leader
3	Consiglio Nazionale delle Ricerche	CNR	Member
4	DTC Lazio	DTC	Member
5	Engineering	ENG	Member
6	Università degli Studi di Bari Aldo Moro	UNIBA	Member
7	Università degli Studi di Ferrara	UNIFE	Affiliated by “convenzione”
8	Università degli Studi di Firenze	UNIFI	Member
9	Università degli Studi di Parma	UNIPR	Affiliated by “convenzione”
10	Università degli Studi di Torino	UNITO	Member

## Executive Summary

This deliverable introduces the technological context referred to virtual technologies applied to museums and art collections.

It is a living document and will be updated whenever necessary to comply with additional information and requirements from the Project Changes coordinator.

## Table of content

DELIVERABLE INFORMATION .....	1
DELIVERABLE HISTORY.....	2
SPOKE INFORMATION.....	3
SPOKE PARTNERS .....	3
EXECUTIVE SUMMARY .....	4
TABLE OF CONTENT .....	5
1. INTRODUCTION .....	6
2. STATE OF THE ART ANALYSIS OF PARTNERS SOLUTIONS.....	7
3. STATE OF THE ART ANALYSIS OF SOLUTIONS APPLIED THE MUSEUM CATEGORIES .....	51
Cat.1: Archaeological Museums (Egyptian Museum Turin) .....	51
Cat.2: Parks (Literary Parks Grazia Deledda, Carlo Levi) .....	57
Cat.3: Demo-ethnic-anthropological-geology-natural history museums (Capellini Museum, SMA Ferrara, Museo Lombroso) .....	62
Cat.4: Historical Monuments, Palaces and House Museums (Reggia Caserta) .....	65
Cat.5: Art collections (CSAC Parma, Galleria Estensi Modena, NAVIGA UNISOB). .....	68
4. PRE-PROTOTYPING ALDROVANDI .....	68
REFERENCES .....	75

## 1. Introduction

The Spoke 4 of the Changes project is dedicated to the identification of virtual technologies that can reply to museums and art collections needs and requirements. WP3 has therefore started to analyse the national and international context, starting from technological solutions already adopted by institutions and from those developed by the partners themselves, studying various exemplary case studies, in line with macro categories. Although the Spoke has set 6 main categories (Type A – high-density and innovative museum; Type B – natural history and scientific museum; Type C – widespread art gallery; Type D – sites museums with tangible and intangible heritage and landscapes with low or no virtual and digital implementations and a particular focus in southern Italy; Type E – historical palaces; Type F – demo-ethnic-anthropological museums with less than 20,000 visitors per year), for the purpose of this deliverable we have considered the following thematic macro categories:

- Cat.1: Archaeological Museums;
- Cat.2: Parks (Literary, History, Archaeological and Naturalistic);
- Cat.3: Demo-ethnic-anthropological museums (including geology and natural history museums);
- Cat.4: Historical Monuments, Palaces and House Museums.
- Cat.5 Art collections (paintings, sculptures, etc.).

Each of these categories has specific problems, potentialities and necessities.

For each of these categories, we have considered as relevant aspects for the selection of the most appropriate technologies, a number of variables and characteristics that could heavily influence the design and implementation of solutions.

Specifically, we have adopted a PACT (People, Activities, Context, Technologies) approach in this analysis (Banyon 2014):

- **People:** Audience (type, numbers, single/groups, Italian/foreigners) and Staff
- **Activities:** Permanent vs Temporary exhibitions, Specific needs and problems to solve
- **Context:** Physical: Collections located in Historical or Modern buildings or Outdoor; Organisational: Scope of the museum
- **Technologies:** Availability of Wi-Fi, Cell/Signal coverage, Previous Experience with Technological solutions, management and maintenance.

The following List of questions is used as reference in the analysis:

- **People** (audience): Who is the main audience (Type, numbers, single/ groups, Italian /foreigners)? Which are the main needs and characteristics?
- **Activities:**

- Scope and Goal: what is the main problem to solve? What are the main needs and requirements?
- Temporal Aspects: How long will the activity last? Regularly? In calm or busy moment?
- Cooperation: Is activity meant to be done together or alone? Does it require cooperation?
- Complexity: Is the activity simple and well defined with little choices? Or complex and need guidance step by step?
- Security: Has the activity potential impact on users' security?
- Content: which Input data is needed? Output? Which are the Requirements referred to in those data?
- **Context:**
  - Physical Space: How is physical space? Climate? Noisy? Echo? Dirty? Wire/Wireless? Open air? Modern/historical? Indoor or outdoor? Dark? Electric plugs?
  - Social Context: Alone or together? Friends or unknown? Language? Religious? Disability? Is feedback sound acceptable?
  - Organisational Context: how's the working environment? Staff? How do people work? Role? Management structure?
- **Technologies:**
  - Media: Which media? Which digital content should be acquired and processed?
  - Hardware: Which visualisation devices? Which Interaction devices?
  - Network: is there a WiFi? Mobile signal? Is it necessary to have a local network?

## 2. State of the art analysis of partners solutions

In this chapter we describe the technological solutions developed or adopted by the partners of the Spoke, and we identify some reference case studies and methodologies that might be used as best practice examples. We have given priority to open-source solutions.

### 2.1 3D and WEB-BASED solutions: the ATON framework

ATON is an open-source framework<sup>1</sup> designed and developed by CNR ISPC (Fanini et al. 2021), based on modern web standards and technologies. It can be used to create Web3D or WebXR applications interacting with Cultural Heritage objects and 3D scenes on the Web. It adopts a “develop once, deploy everywhere” approach, without requiring any installation for final users, with the 3D presentation layer automatically adapting to the device - mobile, desktop, museum kiosks or immersive XR devices.

The modular architecture of the framework and its plug&play approach, offer researchers, professionals and generic stakeholders a wide range of customization, depending on specific project requirements - like user interface (UI), interaction model, etc. Its architecture allows also fast and scalable deployment in different scenarios (offline, local network or internet) and hardware (local workstations, small lab servers, up to large clusters of Research Infrastructures, like H2IOSC - <https://www.h2iosc.cnr.it/>).

The framework also offers a simple but powerful API to manipulate 3D scenes and customize events for rich interactions. This has already allowed several projects to accelerate development and deployment of interactive solutions on the web. The framework also provides advanced functionalities related to the interactive rendering of complex materials, viewpoint management, spatial UIs for XR sessions, real-time collaborative interaction, visual/immersive analytics and integration with complex multimedia content, that allow to craft rich, complex and universal web-based and open-source solutions.

Sample projects using the ATON framework:

- **E-Archeo 3D** (parks) <https://e-archeo.it/output/#earcheo3d>; <https://3d.e-archeo.it/a/ales/> (Figure 1)
- **Vani Virtual Museum** (3D collections): <https://www.vanivirtualexperience.com/interactive-experience>
- **Codex4D** (manuscripts): <https://codex4d.it/> (Figure 2)
- **Brancacci and Cerveteri** (monuments) <https://brancaccipov.cnr.it> (Figure 3 and Figure 4)
- **Extended Matrix** and Emviq tool (excavation) <https://osiris.itabc.cnr.it/scenebaker/index.php/projects/emviq/>
- **Redrask** (3D puzzle game): <http://www.backtothefuture.polito.it/TemplePuzzle3D.html>

---

<sup>1</sup> <https://github.com/phoenixbf/aton>

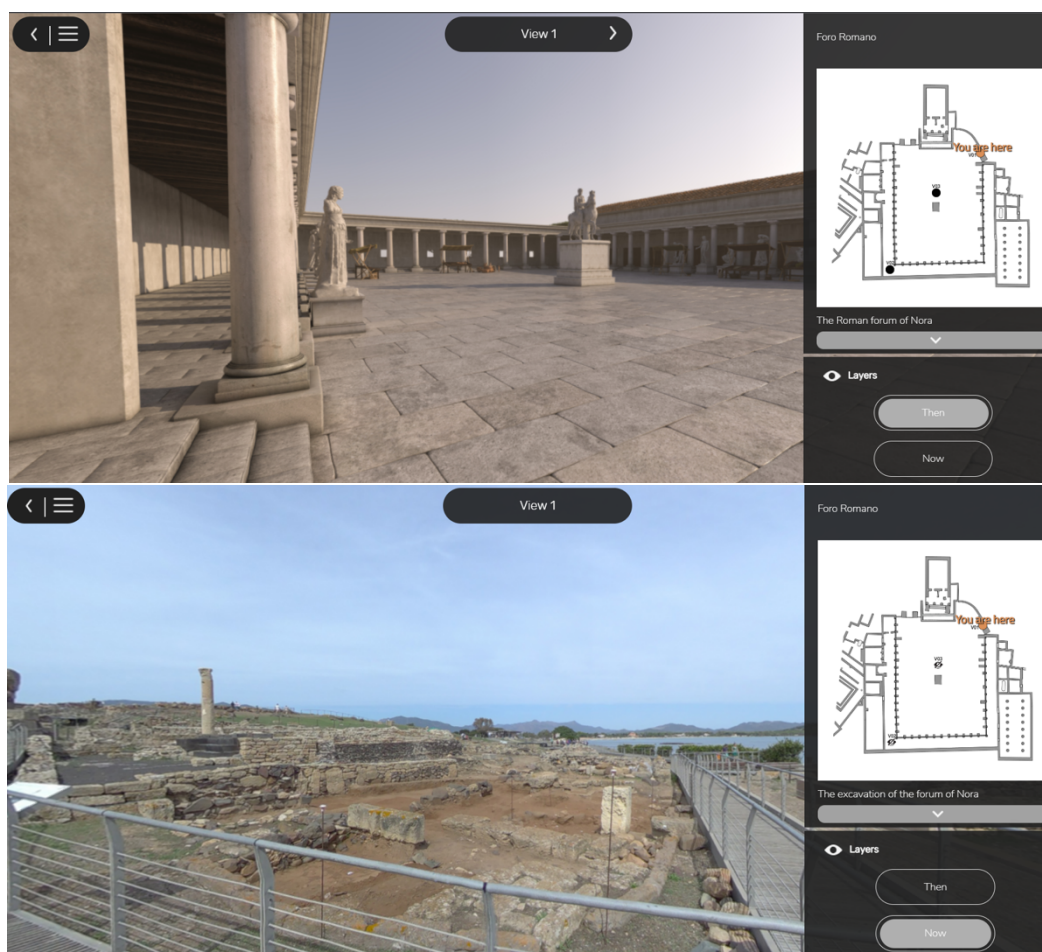


Figure 1. E-archeo interface: Nora archaeological Park (Roman temporal level) and interface of Nora Park (nowadays temporal level)





Figure 2. Codex4D app: interactive exploration of semantically-enriched 3D manuscripts with discovery (infrared lens)

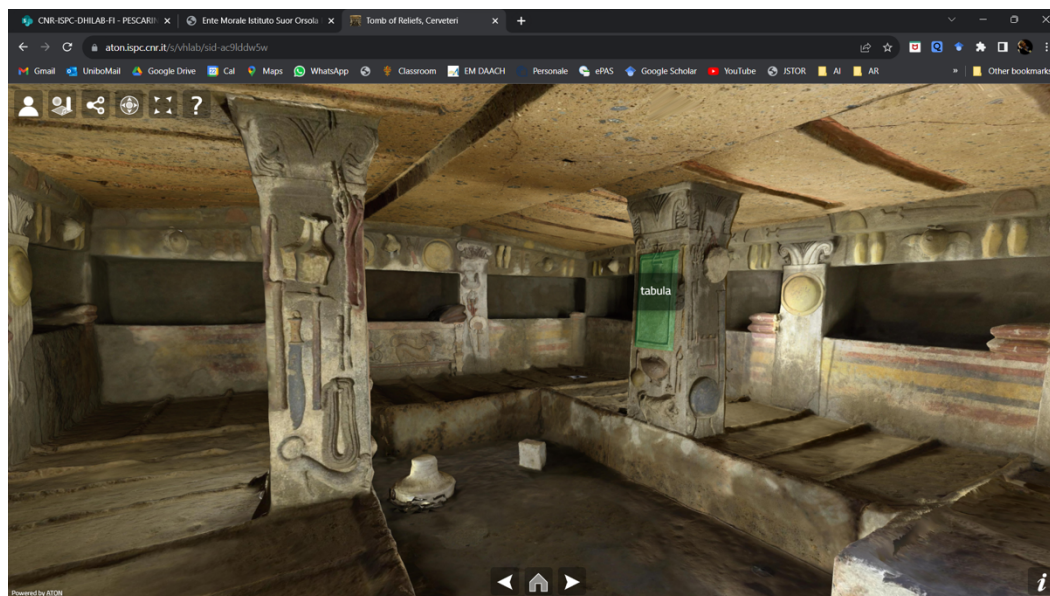


Figure 3. Cerveteri tomb 3d interactive exploration





Figure 4. BrancacciPOV hybrid and XR experience (the guide, visitors with tablets, visitors with Oculus)

## 2.2 Augmented Reality and AI

University of Florence (Media Integration and Communication Center MICC) has worked within the ReInHerit project and developed a technologies based on Augmented Reality and Machine Learning that could be of high interest, if adapted and re-used, for Italian museums and specifically for Category 5 (Art Collections). Within ReInHerit, an Horizon2020 project (<https://www.reinherit.eu/> grant number 101004545), specific apps have been developed, such as “Face-Fit” and “Strike a Pose”.

**Face-Fit** application has been developed in JavaScript on the client side and in Python on the server side. The app uses the MediaPipe network to understand the pose and expression of users and evaluate how similar they are w.r.t. those depicted in an artwork. MediaPipe is a framework for building multimodal machine learning pipelines, which includes a neural network for face landmark recognition. The MediaPipe face landmark recognition neural network uses a combination of convolutional neural network (CNN) and regression layers to predict the coordinates of facial landmarks. The network takes an image or video frame of a human face as input and outputs a list of coordinates for each facial landmark.

Pose detection on the human bodies is achieved using TensorflowJS 1 detection API exploiting the pose detection model, MoveNet. The model runs completely client-side in the browser. Server-side an SQLite database is used to stores artworks'collections, challenges and artworks' metadata and descriptions.

**Strike-a-pose** is a web application which performs analysis and evaluation of human poses compared to poses present in famous paintings or statues. The user is challenged to reproduce in sequence the poses of some artworks from the museum's collections. Once all the poses have been matched, the application allows the user to generate a video that

can be saved for any social sharing and provide info on the artworks. The video shows the user matching process and the overall interactive experience lived at the museum. The app won a Best Demo Honorable Mention award at ACM Multimedia 2022, the foremost conference on multimedia.

The free Codes of the App are available at <https://github.com/ReInHerit/strike-a-pose>

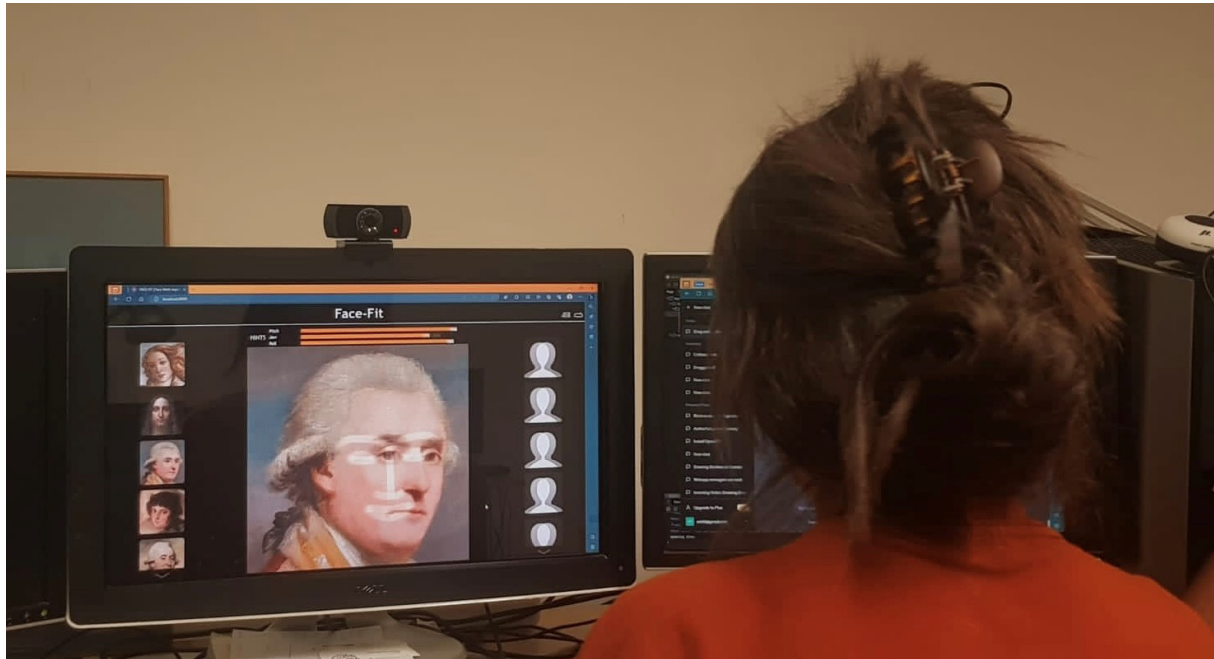


Figure 5. Face-Fit interface

### 2.3 3d Printing and Tangible Interaction

This Section presents the state of the art of 3D-based technologies developed by the Reverse Engineering and Virtual Prototyping (ReViP) Team of Department of Industrial Engineering, University of Florence (UNIFI), co-led by Prof. Rocco Furferi, member of the CHANGES consortium on behalf of UNIFI.

In detail, this section presents the following technologies:

- 1) Device and methods for enhancing the inclusion of visually impaired people in enjoying artworks
- 2) Devices for the Reverse Engineering and 3D imaging of artworks and architectural heritage and 3D reconstruction of archaeological sites
- 3) 3D Printing devices for the physical reconstruction of artifacts replica

#### 2.3.1. Device and methods for enhancing the inclusion of visually impaired people in enjoying artworks

Lack of sight affects blind people's possibilities in many aspects of everyday life. Movements, tasks and actions that are simple, or even trivial, to sighted people become really challenging for blind people (BP). To support BP in a great number of situations, in the last decades many devices have been designed all over the world. In most cases, research has been focused on developing systems for assisting BP in their everyday activities such as walking (Klatzky, 1987), reading books, using computers (Streri, 1988) and so on. However, there are other blind people needs that, although not essential for living, contribute to the overall well-being of an individual. The possibility of enjoying artworks is probably one of the most relevant one since it helps BP in taking part, on an equal basis with others, in cultural life. Not surprisingly, some museums (e.g., the Omero Tactile Museum of Bologna or the Art Institute of Chicago) have created tactile exhibitions dedicated to blind people. The majority of museums, however, present touchable reproductions of sculptures or other 3D objects; tactile 3D reproductions of pictures or other 2D artworks are very rare and only a few institutions have them at their disposal. Usually, these models are handmade by artists thus offering artistic 3D interpretations of the 2D original artwork. To increase and speed-up this "translation" process, in the last few years a few computer-aided approaches have been developed (Reichinger et al., 2012; Carfagni et al., 2012 and Thompson et al., 2006).

Explicitly dealing with relief reconstruction from single images, some significant studies can be found in literature, especially on coinage and commemorative medals (see for instance Wu et al. 2014 and Wu et al. 2013). In most of the proposed approaches the input image, often representing human faces, stemmas, logos and figures standing out from the image background are translated into a flat bas-relief by adding volume to the represented subjects. The easier, and probably best known, method to perform a bas-relief reconstruction from images is image embossing (Huang et al. 2011 and Song et al. 2007), a widely recognized computer graphics technique in which each pixel of an image is replaced either by a highlight or a shadow, depending on boundaries on the original image. The result obtained using this technique consists of a relief visually resembling the original image but affected by shallow and incorrect depth reconstruction (due to the algorithm based on image gradient computation). Some improvements to this method, like the one proposed by Sourin et al., 2001, just to cite a few, are in scientific literature; the embossing method is enhanced by using pre-processing techniques based on image enhancement, histogram equalization and dynamic range. The uses of unsharp masks and smoothing filters have also been extensively adopted to emphasize salient features and deemphasize others in the original image, so that the final results better resemble the original image. In a more recent paper (Li et al. 2012) an approach for estimating the height map from single images representing brick and stone reliefs (BSR) has been also proposed. The method proved to be adequate for restoring BSR surfaces by using a height map estimation scheme consisting of two levels: the bas-relief, referring to the low frequency component of the BSR surfaces, and the high frequency detail. Commercial software, like ArtCAM and JDPaint (see Wang

et al. 2010) have been also developed making available functions for bas-relief reconstruction from images.

The inverse problem of creating 2.5D models starting from 3D models has also been extensively studied (Weyric et al., 2007 and Kerber, 2007). These techniques use normal maps obtained by the (available) 3D model and use techniques for performing the compression in the 2.5D space. However, these works are not suitable for handling the reconstruction from a 2D scene where normal map is the desired result and not a starting point. One of the most important methods aimed at building models visually resembling sculptors-made bas-relief from paintings is the one proposed by Reichinger et al., 2011. In this work the high-resolution image of the painting to be translated into bas-relief is manually processed to 1) extract the painted subject's contours, 2) identify semantically meaningful areas and 3) assign appropriate height values to each area. One of the results consists of "a layered depth diagram" made of several individual shapes cut out of flexible sheets of constant thickness, which are glued on top of each other to resemble a painting". Once the layered depth is built, in the same work, a method for extracting textures from the painted scene and for assigning them to the 2.5D model is drawn. Some complex shapes, such as subject faces, are modelled using an appositely devised software package and the resulting normal maps are finally imported into the model and blended. The result consists of a high-quality texturized relief. While this approach may be extremely useful in case perspective related information is lacking in the considered paintings, it is not the best option in case of perspective paintings. In fact, the reconstructed scene could be geometrically inconsistent, thus causing misperception by blind people. This is mainly because the method is required to manually assign height relations for each area regardless of the information coming from scene perspective. With the aim of reducing the error in reconstructing shapes from image shading, the most studied method is the so-called Shape From Shading (SFS). Extensively studied in the last decades (Daniel and Dourou, 2000; Di Angelo and Di Stefano, 2012 and Frankot and Kellappa, 1988), SFS is a computational approach that bundles several techniques aimed to reconstruct the three-dimensional shape of a surface shown in a single grey-level image. However, automatic shape retrieval using SFS techniques proves to be unsuitable for producing high-quality bas-reliefs (Weyrich, 2007) therefore, more recent work by several researchers has shown that moderate user-interaction is highly effective increasing 2.5D models from a single view. Moreover, Wu et al., 1988 proposed a two-step procedure: the first step recovers high frequency details using SFS; the second step corrects low frequency errors using a user-driven editing tool. However, this approach entails quite a considerable amount of user interaction especially in the case of complex geometries. Nevertheless, in case the amount of required user interaction can be maintained at a reasonable level, interactive SFS methods may be considered among the best candidate techniques for generating good quality bas-reliefs starting from single images.

Unfortunately, since paintings are hand-made artworks, many aspects of the represented scene (such as silhouette and tones) are unavoidably not accurately reproduced in the image, thus leading to an even more complex task in performing reconstruction with respect to the analysis of synthetic or real-world images. In fact, image brightness and illumination in a painting are only an artistic reproduction of a (real or imagined) scene. To make things even worse, light direction is unknown in most cases and a diffused light effect is often added by the artist to the scene. Furthermore, real (and represented) objects surfaces may have complex optical properties, far from being approximated with Lambertian surfaces. These drawbacks have great impact on the reconstruction: any method used for retrieving volume information from paintings shall be able to retrieve 3D geometry based on defective information. Consequently, any approach for solving such a complex SFS-based reconstruction shall require several additional simplifying assumptions and a worse outcome is always expected with reference to results obtained for synthetic and real-world images. With these strong limitations in mind, the ReViP group provided a valuable attempt in providing sufficiently plausible reconstruction of artistically reproduced shaded subjects/objects. The main aim is to provide a systematic user-driven methodology for the semi-automatic generation of tactile 2.5D models to be explored by visually impaired people. The proposed methodology lays its foundations on the most promising existing techniques; nonetheless, due to the considerations made about painted images, a series of novel concepts are introduced in this paper: the combination of the spatial scene reconstruction and the volume definition using different volume-based contributions, the possibility of modelling scenes with unknown illumination and the possibility of modelling subjects whose shading is only approximately represented. The method does not claim to perform a perfect reconstruction of painted scenes. It is, rather, a process intended to provide a plausible reconstruction by making a series of reasoned assumptions aimed at solving a number of problems arising from 2.5D reconstruction starting from painted images. The devised methodology is supported by a user-driven graphical interface, designed with the intent of helping non-expert users (after a short training phase) in retrieving final surface of painted subjects (see Figure 6).





Figure 6. – A screenshot of the GUI, designed with the intent of helping non-expert users in retrieving final surface starting from painted images.

The description of the tasks carried out to perform reconstruction will be described with reference to an exemplificative case study i.e., the reconstruction of “The Healing of the Cripple and the Raising of Tabitha” fresco by Masolino da Panicale (see Figure 7). This masterpiece is a typical example of Italian Renaissance paintings characterized by single-point perspective. With the aim of providing a robust reconstruction of the scene and of the subjects/objects imagined by the artist in a painting, the systematic methodology relies on an interactive Computer-based modelling procedure that integrates the following tasks:

1. *Preliminary image processing-based operation on the digital image of a painting; this step is mainly devoted to image distortion correction and segmentation of subjects in the scene.*

A digital copy of the original image to be reconstructed in the form of bas-relief is acquired using proper image acquisition device and illumination. Image acquisition should be performed with the intent of obtaining a high-resolution image which preserves shading since this information is to be used for virtual model reconstruction. This can be carried out using calibrated or uncalibrated cameras. Referring to the case study used for explaining the overall methodology, the acquisition device consists of a Canon EOS 6D camera (provided with a 36 x 24 mm<sup>2</sup> CMOS sensor with a resolution equal to 5472 X 3648 pixel<sup>2</sup>). A CIE standard illuminant D65 lamp placed frontally to the painting was chosen to perform a controlled acquisition. The acquired image is properly undistorted (by evaluating lens distortion) and rectified using widely recognized registration algorithms (Brown, 2008). Since both scene reconstruction and volumes definition are based on grey-scale information, the colour of such an image must be discarded. In this work, colour is discarded by performing a colour conversion of the original image from sRGB to CIELAB colour space and by extracting the L\* channel. In detail, a first colour conversion from sRGB colour space to the tristimulus values CIE XYZ is carried out using the equations available for the D65 illuminant.

Then, the colour transformation from CIE XYZ to CIELAB space is performed simply using the XYZ to CIELAB relations. The result consists of a new image where the channel  $L^*$  is extracted thus defining a grayscale image that can be considered the starting point for the entire devised methodology (see Figure 7).



Figure 7 - grayscale image obtained *using  $L^*$  channel of*

Once the image is obtained, the different objects represented in the scene, such as human figures, garments, architectural elements, and so on, are properly identified. This task is widely recognized with the term "segmentation" and can be accomplished using any of the methods available in literature (e.g., Nadernejad et al., 2008). In the present work segmentation is performed by means of the developed GUI, where the objects outlines are detected using the interactive livewire boundary extraction algorithm (Barrett and Mortensen, 1997). The result of segmentation consists of a new image where different regions (clusters) are described by a different label (see for instance Figure 8 where the clusters are represented in false colors) with  $i = 1...k$  and where  $k$  is the number of segmented objects (clusters). Besides image segmentation, since the volume definition techniques detailed in next sections are mainly based on the analysis of the shading information provided by each pixel of the acquired image, another important operation to be performed on image consists of albedo normalization. In detail it is necessary to normalize the albedo of every segment, which is pixel-by-pixel the amount of diffusively reflected light, to a constant value. For sake of simplicity, it has been chosen to normalize the albedo to 1, and this is obtained by dividing the grey channel of each segment by its actual albedo value.



Figure 8 - Example of a segmented image (different color represents different segment/region).

The results of this preliminary image-processing based phase are: 1) a new image representing the grayscale version of the acquired digital image with corrected albedo and 2) clusters each one representing a segment of the original scene.

## 2) Perspective geometry-based scene reconstruction

Once the starting image has been segmented it is necessary to define the properties of its regions, in order to arrange them in a consistent 2.5D scene. This is because the devised method for retrieving volumetric information (described in the next sections) requires the subject describing the scene to be geometrically and consistently placed in the space but described in terms of flat regions. In other words, a deliberate choice is made by the authors here: to model, in the first instance, each subject (i.e., each cluster) as a planar region thus obtaining a virtual flat-layered bas-relief (visually resembling the original scene but with flat objects) where the relevant information is the perspective-based position of subjects in the virtual scene. Two reasons are supporting this choice: firstly, psychophysical studies performed with blind people documented in Carfagni et al., 2012 demonstrated that flat-layered bas-relief representation of paintings are useful for a first rough understanding of the painted scene. Secondly, for each subject (object) of the scene, the curve identified on the object by the projection along the viewing direction (normal to the painting plane) approximately lays on a plane if the object is limited in size along the projection direction i.e., when the shape of the reconstructed object has limited size along the viewer direction (see Figure 9). Since the final aim of the present work is to obtain a bas-relief where objects slightly detach from the background, this assumption is considered valid for the purpose of the developed method.



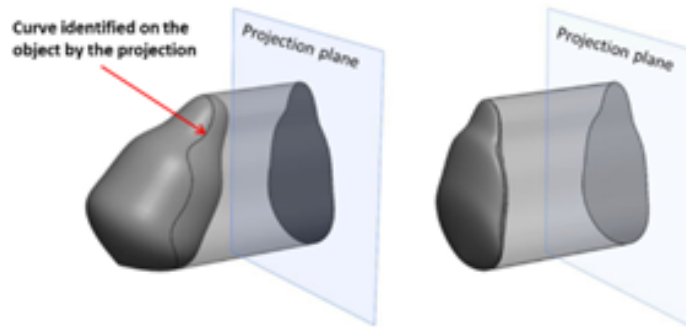


Figure 9 - Curve identified on the object by the projection along the viewing direction.

Several methods for obtaining 3D models from perspective scenes are in literature, proving to be very effective for solving this issue. Most of them, and in particular the method provided by Horry et al., 1997, can be successfully used to perform this task. Or, at most, combining the results obtained using [8] with the method described in Reichinger et al. 2011 for creating layered depth diagrams, this kind of spatial reconstruction can be accomplished. As stated in the introduction, however, one of the aims of the present work is to describe the devised user-guided methodology for 2.5D model retrieval ab initio to help the reader in getting the complete sense of the method. For this reason, a method for obtaining a depth map of the analyzed painting, where subjects are placed in the virtual scene coherently with the perspective, is provided below. A further point to underline is that, differently from similar methods in literature, oblique planes (i.e., planes represented by trapezoid whose vanishing lines do not converge in the vanishing point) are modelled using the proposed method.

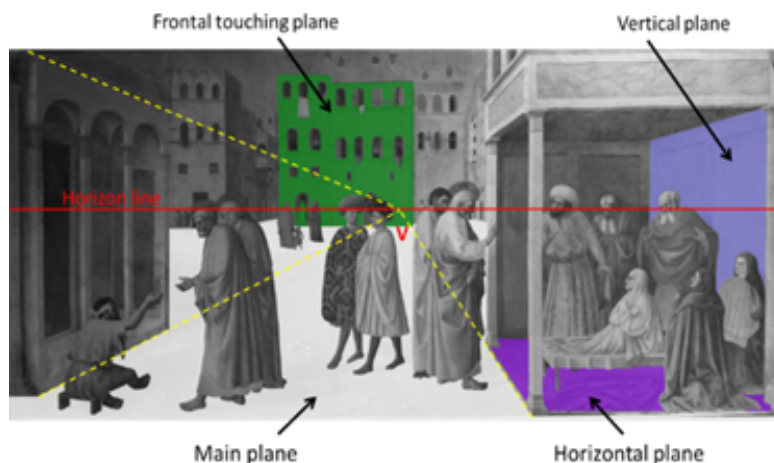


Figure 10 - Some examples of planes detectable from the painted scene.

This statement can be justified by observing that once selected the frontal and/or oblique planes, only horizontal and vertical planes remain and that no horizontal plane can cross the horizon line (they are entirely above or below it). The only horizontal plane (i.e., parallel to the ground) which may “intersect” the horizon line is the one passing through the viewpoint (i.e., at the eye level) and whose representation degenerates in the horizon line itself. If no intersections with the horizon line are found, intersections between the plane and the line passing through the vanishing point and perpendicular to the horizon are sought. If an intersection of this kind is found the plane type is necessarily horizontal. Among the detected horizontal planes, it is possible to manually detect the so-called “main plane” i.e., a plane taken as a reference for a series of planes intersecting it in the scene. Looking at most of renaissance paintings, usually such a plane corresponds to the ground (floor). If no intersections with either the horizontal line or with its perpendicular are found, the automatic classification of the plane is not possible; consequently, it is requested to manually specify the type of the plane via direct user input.

In conclusion, once all the planes are assigned a proper gradient, the result consists of a grayscale image corresponding to a height map (see Figure 11). Accordingly, this representation consists of a virtual flat-layered bas-relief. Of course, this kind of representation performs well for flat or approximately planar regions like, for instance, the wooden panels behind the three figures surrounding the seated woman (Tabitha). Conversely, referring to the Tabitha figure depicted in Figure 10, the flat-layered representation is only sufficient to represent its position in the virtual scene while its shape (e.g., face, vest etc.) needs to be reconstructed in terms of volume.



Figure 11 - Final greyscale height-map of “The Healing of the Cripple and the Raising of Tabitha”.

### 3) Volume reconstruction

Once the height map of the scene and the space distribution of the depicted figures have been drafted, it becomes necessary to define the volume of every painted subject, for which is possible, for the viewer, to figure out its actual quasi-three-dimensional shape. As previously stated, to accomplish this purpose, it is necessary to translate in shape details all the information elicited from the painting. First, all objects resembling primitive geometry in the scene are reconstructed using a simple user-guided image processing-based procedure. The user is asked to select the clusters whose final expected geometry is ascribable to a primitive, such as a cylinder or a sphere. Then, since any selected cluster represents a single blob (i.e., a region with constant pixel values) it is easy to detect its geometrical properties like, for instance: centroid, major and minor axis lengths, perimeter and area. Based on such values, it is straightforward to discriminate between a shape that is approximately circular (i.e., a shape that must be reconstructed in the form of a sphere) or approximately rectangular (i.e., a shape that must be reconstructed in the form of a cylinder), using widely known geometric relationships used in blob analysis. After the cluster is classified as a particularly shaped object, a gradient is consistently applied. If the object to be reconstructed is only partially visible in the scene, it is up to the user to manually classify the object. Then, for cylinders the user shall select at least two points defining its major axis while, for spheres, he is required to select a point approximately located in the circle center and two points roughly defining the diameter. Once these inputs are provided the greyscale gradient is automatically computed (Volpe et al., 2012).

#### *4) Virtual bas-relief reconstruction*

Using a devised GUI, it is possible to interactively combine the contributions of perspective-based reconstruction, SFS, rough and fine detail surfaces. It is possible to decide the optimum weights for the different components and to assess how much relief is given to each object with respect to the others. Users are allowed to select the weight by means of relative sliders, showing in real-time the aspect of the final surface (see Figure 12). In this phase, the system prevents the user from generating, for a given object, a surface whose relief exceeds the one of other objects closer to the observer.

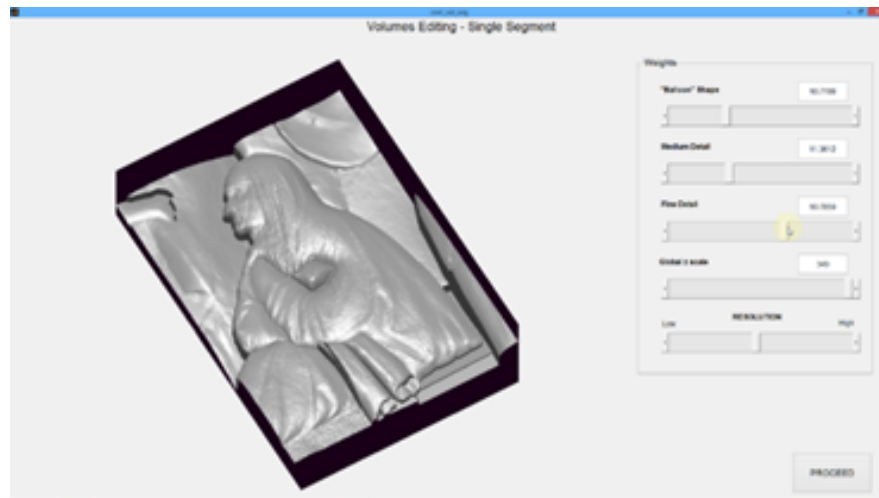


Figure 12 - GUI devised for interactively combining the contributions from perspective-based reconstruction, SFS, Inflated and Fine detail surfaces.

In Figure 13 the virtual 2.5D model (bas-relief) obtained by using the devised procedure is depicted. To appreciate the differences between the perspective geometry-based reconstruction and the volumes-based one (Furferi et al., 2014; Governi et al., 2014).

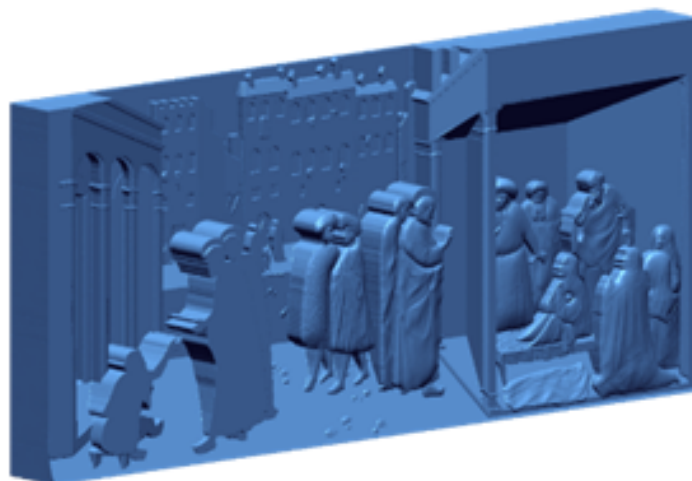


Figure 13 - 2.5D virtual model obtained by applying the proposed methodology on the image of Figure 2. On the left part of the model, the flattened bas-relief obtained from the original image is shown; on the right part of the model the complete reconstruction is provided.

### *Rapid prototyping of the virtual bas-relief*

Once the final surface has a satisfying quality, the procedure allows the user to produce a STL file, ready to be manufactured with reverse prototyping techniques or CNC milling machines. In Figure 14, the CNC prototyped model for "The Healing of the Cripple and the

"Raising of Tabitha" is shown. The physical prototype is sized about 900 mm x 400 mm x 80 mm. In the same figure, a detail from the final prototype is also shown.



Figure 14 - Prototype of "The Healing of the Cripple and the Raising of Tabitha" obtained by using a CNC.

The devised method was widely shared with both the Italian Union of Blind and Visually Impaired People in Florence (Italy) and experts working in the Cultural Heritage field, with mention to experts from the Musei Civici Fiorentini (Florence Civic Museums, Italy) and from Villa la Quiete (Florence, Italy). According to their suggestions, authors realized a wide range of bas-reliefs of well-known artworks of the Italian Renaissance including "The Annunciation" of Beato Angelico (see Figure 16) permanently displayed at the Museo di San Marco (Firenze, Italy), some figures from the "Mystical marriage of Saint Catherine" by Ridolfo del Ghirlandaio (see Figure 17) and the "Madonna with Child and angels" by Niccolò Gerini, both displayed at Villa La Quiete (Firenze, Italy).



Figure 16 - Prototype of "The Annunciation" of Beato Angelico placed in the upper floor of the San Marco Museum (Firenze), next to the original Fresco.





Figure 17 - Prototype resembling the Maddalena and the Child figures retrieved from the "Mystical marriage of Saint Catherine" by Ridolfo del Ghirlandaio and prototype realized for "Madonna with Child and angels" by Niccolò Gerini.

### 2.3.2. Devices for the Reverse Engineering and 3D imaging of artworks and architectural heritage and 3D reconstruction of archaeological sites

Numerous works in scientific literature propose 3D reconstruction of artworks for use in VM or to fill virtual collections (Song et al., 2011). In fact, the work on 3D digitization procedures and publication pipelines within the Europeana Tech community serves as evidence that 3D digitization of cultural heritage has recently become a regular procedure. All literature procedures share the same approach encompassing 3D data acquisition and 3D model reconstruction. However, depending on the historical or artistic source, different outcomes could be expected, as stated in Sander et al., 2019). In the context of architectural history, they facilitate research and presentation, and have a growing significance for the long-term preservation, investigation, and provision of public access to tangible, intangible, and digital cultural heritage. In the broader context of cultural heritage, 3D reconstruction is instead meant to support data collecting, such as through digitization, data retrieval from database records with the transfer of knowledge, reconstructing, replicating, and producing artifacts and examining visual humanities questions, such as a collection of intricate figurative paintings. Reconstruction in three dimensions is also used to investigate and assess sources. Sometimes the focus of research is on schemes and systems rather than a particular object, such as when looking into the Vitruvian system of architectural orders (see Ling et al. 2007). Considering this, 3D reconstruction techniques are frequently used to derive archetypes or specific traits. Such a process involves the question concerning the originality of reconstructed digital models i.e., how much the digital twin resembles the original artwork. According to Ling et al. 2007 the relationship between the artwork and its digital 3D representation depends on data quality assessment, visualization, historical preparation processes, conceptualization and contextualization.

One of the best technologies for reality documenting is 3D imaging/scanning since it can digitize objects with high resolution and capture precise surface data and distance information in a relatively quick and simple manner. This is especially true if the artwork is a sculpture, bas-relief, or piece of architecture. 3D recording enables digital reconstruction of the artworks as well as the creation of extensive archives of significant artifacts. The ability to replicate the measurements and volumetric representation of scanned artifacts with high precision is the key benefit of 3D scanning in the field of cultural and historical asset preservation.

As is well known, there are numerous ways to obtain a 3D model of a three-dimensional work of art. The most significant techniques are photogrammetry, laser scanning, structured light scanning, RGB-D-based imaging, and computer tomography. Photogrammetry is a technique for creating 3D models from many pictures of an object taken from various perspectives. The first advances in photogrammetry were made in the surveying industry to imitate topography but rapidly evolved to also study architectural sites. A recent study (Kingsland, 2020) evaluated the performance of three digital photogrammetry processing software, namely Agisoft Metashape, Bentley ContextCapture, and RealityCapture demonstrating their effectiveness despite some differences in terms of overall performance can be retrieved. In Remondino, 2011 a review of optical 3D measurement sensors and 3D modeling techniques, with their limitations and potentialities, requirements and specifications is provided. Although such work is rather dated, especially in relation to the incredible developments of the last five years, it is evident that these techniques were already state-of-the-art 15 years ago. However, some issues that are still a challenge in this field today were brought up in such a work: first, it is critical to choose the right methodology (i.e., sensor, hardware, and software) and data processing procedure. The right production workflow should then be designed in order to ensure that the finished product meets all the required technical requirements. The data processing time is required to be sped up with as much automation as is practical, but accuracy must always come first.

Structured-light 3D scanning projects a set of organized patterns of light onto an object. When a narrow band of light is projected onto a surface that has been three-dimensionally built, a line of illumination is produced that can be used to geometrically reconstruct the shape of the surface from perspectives other than the projector's. The capture of a high number of samples at once makes pattern projection, which consists of many stripes at once or of arbitrary fringes, a faster and more adaptive method. The fundamental idea behind laser scanning is the exchange of a laser signal between an emitter and a receiver, who then receives the return signal. The scanner uses a variety of distance-calculating techniques to

identify the type of equipment during the receiving phase. The distance between the laser's emission and reception is measured in terms of "time of flight" (TOF) for 3D laser scanners, or it is measured in terms of "phase difference" (Phase shift based) when the calculation is made by comparing the phases of the emitted signal and the return signal. Due to the rapid movement of the body and the mirror, data can be gathered at rates of up to a million points per second. Whatever method is used, the result is a 3D point cloud of the scanned object, which can then be processed further using specialized software programs capable of reconstructing the 3D geometry of the scanned object in terms of surfaces.

Another relevant example is the Digital Humanities project Florence As It Was (<http://florenceasitwas.wlu.edu>), which aimed to reconstruct the architectural and decorative appearance of late Medieval and early Modern buildings. In such a project 3D point cloud models of buildings (i.e., existing structures like chapels, churches, etc.) are combined with 3D rendered models of artworks that were installed inside of them during the fourteenth and fifteenth centuries. Also in this work, the key steps outlined in the optimized workflow are based on the conduction of art historical research to identify the original artworks in each building, the use of 3D scanning (e.g., LiDAR) to obtain 3D data, using high resolution photogrammetry to capture artworks and creating point clouds to be further manipulated. An important issue to be considered when dealing with 3D acquisition of artworks is that when huge objects are being reconstructed using small, high-resolution 3-D imaging devices, there are frequently uncontrollable metric errors involved in the construction of three-dimensional virtual models using optical technologies. Metric accuracy is a significant concern within Cultural Heritage, and there are no current solutions for managing and improving it. Therefore, research is putting efforts in solving this issue, for instance by integrating different acquisition techniques (e.g., 3D range camera systems with optical tracking techniques or 3D reality-based models from image merged with range-based techniques).

As a final remark, it is important to highlight the relevance that 3D scanning could have in terms of students and young people's engagement in CH. In "Crowdsourcing Cultural Heritage: From 3D Modeling to the Engagement of Young Generations", just to cite a successful example, It was possible to construct an organized system of a production cycle that starts with the museum, involves the visitor, returns to the museum, and then moves to the community through the use of existing low cost 3D collection tools (which are very simple to use and readily available on the market). In such a way young people and students become an active part in the process of gaining knowledge in the field, acting as "digital 3D



invaders" engaged in a bottom-up system of social media (Facebook, Twitter, Instagram)-based cultural heritage enhancement.

To deal with this topic, the UNIFI group has several devices and software packages dedicated to Reverse Engineering. In particular:

- ✓ Scanner Romer Absolute ARM 7525 RS1
- ✓ ARTEC-Eva
- ✓ ARTEC-Space Spider
- ✓ NEXTENGINE Desktop 2020I
- ✓ Geomagic DesignX
- ✓ Geomagic ControlX
- ✓ Polyworks
- ✓ Artec Studio Professional

It was first identified, among the many museums rooted in the area, a museum that had available both three-dimensional objects (such as sculptures) and pictorial works of some significance on which, subsequently, to proceed with the reconstruction steps with the devised algorithms.

The aforementioned selection decided on the San Marco Museum since it housed various types of works inside. The museum's fame is mainly due to the paintings of Beato Angelico, one of the greatest painters of the Renaissance, who frescoed many rooms in the Dominican convent of San Marco. Other paintings by Angelico, of various provenance, were collected there in the 20th century, so the museum offers an extraordinary documentation of the painter's activity. Other masters represented in this museum are Fra' Bartolomeo, Domenico Ghirlandaio, Alesso Baldovinetti, Jacopo Vignali, Bernardino Poccetti, Giovanni Antonio Sogliani and others. The lapidary also contains the remains of buildings demolished during the period of the Restoration of Florence as a capital city (from 1865-1871). For the stage of reconstructing a three-dimensional object with which to benchmark, it was decided to reconstruct a "15th-century peduccio" that was of special historical interest.



Figure 18 - "15th-century peduccio" available in the San Marco Museum

Given the need to have available the virtual three-dimensional model of the pedestal, the three-dimensional laser scanner (thus capable of not damaging the specimen in question) "Romer Absolute Arm SI" produced by Hexagon was used. The characteristics of such a scanner, some images of which can be seen in Figure 19, allowed a wide acquisition range at an accuracy in the reconstruction of the three-dimensional model sufficient to perform the above benchmarks.

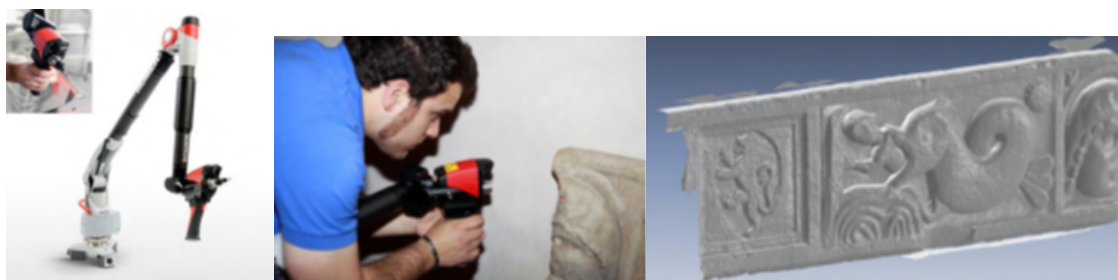


Figure 19 - 3D scan of the peduccio and final result

The technology at the s.o.a. available by UNIFI researchers allows also to acquire architectural heritage. In the subsequent figure, the hall where the peduccio is exposed is shown in planar view (see Figure 20).



Figure 20 – Planar view of the museum hall

Further examples from ReViP are the reconstruction of the Brancacci Chapel (Firenze, Italy) and the reconstruction of the Statue of the Penitent Magdalene (Donatello) - Museo dell'Opera del Duomo, Firenze, Italy (see Figure 21).

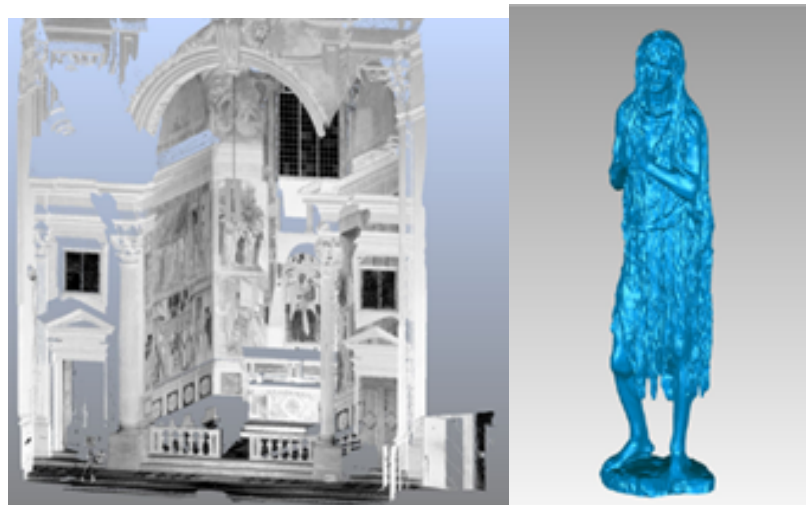


Figure 21 Reconstruction of the Brancacci Chapel (Firenze, Italy) and the reconstruction of the Statue of the Penitent Magdalene by Donatello (Museo Opera del Duomo, Firenze, Italy)

### 2.3.3. 3D Printing devices for the physical reconstruction of artifacts replica

The potential for 3D printing replicas that can be accessed by visitors or even used to replace original artworks, for example, when the latter is damaged or destroyed, is another crucial factor to consider when dealing with the creation of Virtual Museums or exhibitions. This can be done by leveraging Additive Manufacturing (AM) techniques for the creation of such replicas.

As widely recognized, AM is a computer-controlled Manufacturing process (also named 3D Printing) that creates three dimensional objects by depositing materials, usually in layers. Binder jetting, directed energy deposition, material extrusion, powder bed fusion, sheet lamination, vat polymerization, and wire arc additive manufacturing are some of the (Rasive et al. 2021) several AM methods adopted in many engineering fields (Rasive et al. 2021). Accompanied with their own standards, such methods are successfully employed for CH. The New York Metropolitan Museum of Art has significantly encouraged people to engage with its collections online. Visitors can take pictures of museum exhibits to use as the basis for their own digital models. The Met has even provided instructions for doing this in a booklet that is available online. The article points readers toward online tutorials and suggests which software to use. They also go through how to buy a 3D printer or kit or how to use a 3D printing service. The use of 3D printing to preserve cultural treasures and artifacts is an amazing and challenging application. Due to physical deterioration, robbery, and demolition, society continues to lose priceless relics from the past. 3D printing provides a novel way to preserve these items and make them accessible to future generations. To illustrate this point, two archaeologists from the Harvard Semitic Museum recreated a ceramic lion in 2012 using 3D modelling and printing.

Three thousand years ago, during an assault on the historic Mesopotamian city of Nuzi, the original sculpture was destroyed. The fragments are kept in the museum's collection. These were painstakingly captured from hundreds of different perspectives. A computer model was then made using photographs. The incompleteness of the fragments resulted in certain holes in the model. They had to use entire statue scans that were also located in the same area because of this. After digitally reassembling it, they were able to produce a 3D printed replica for display.

Another example is the reconstruction of the ruined Nimrud Lion (see Figure 22) in Iraq.



Figure 22 - 3D printed replica of the Nimrud Lion.

Additionally, accurate replicas can be constructed for exhibitions where the original work cannot be transported, as in the case of Michelangelo's David, which will be on display at the Dubai Expo in 2021. Finally, AM-based models of artwork can be utilized to enhance visitor engagement or for teaching objectives. 3D imaging, combined with Additive Manufacturing, allows to take irreplaceable artifacts seen only in museums and "put them in the hands" of learners. Some important Museums which worked on this topic are the Smithsonian Museum and the British Museum. Reproduction is possible for pieces that must be handled carefully. This makes it possible to examine things closely without endangering the originals. Items that are too delicate to show can be kept safely in storage while a copy is used in their place. Even replicas of damaged artifacts are possible. Before printing a "fixed" model, fragments are scanned and digitally pieced back together. These can be shown side by side in museums to give visitors a better idea of the object's previous appearance. To deal with the topic of AM in the CH field the ReViP group has several devices, as depicted in Figure 23.



Figure 23 – AM devices available in the Laboratory of ReViP

Some other examples are the reconstruction of the Museo di Storia della Scienza in Florence (Italy), the reconstruction of Cappella Brancacci Museum (Florence), the Dante's sculpture in Santa Croce (Florence), the reconstruction of the Giovanni Battista Church in Matera (Italy).

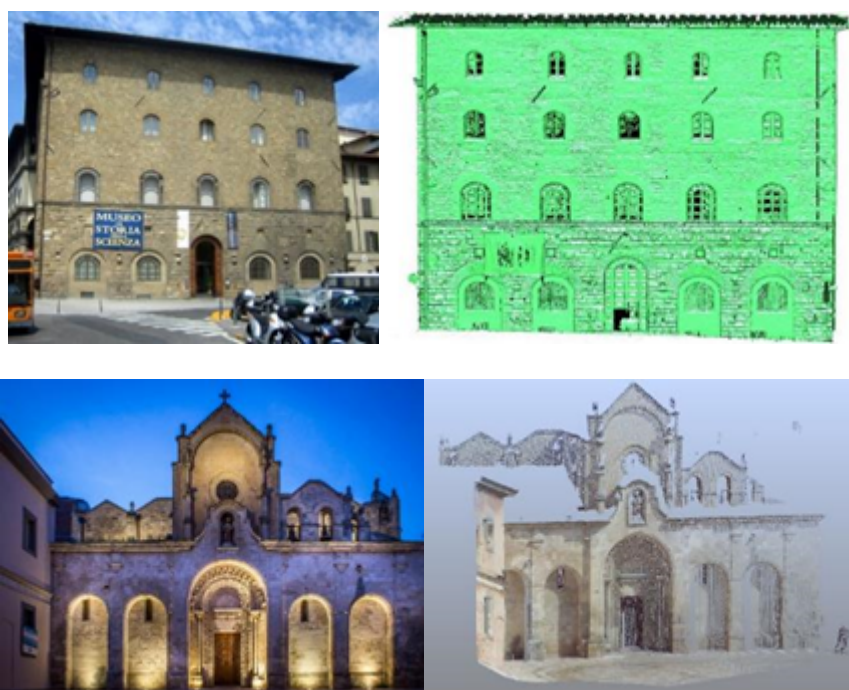


Figure 24 – Examples of 3D reconstruction of architectural heritage performed by UNIFI.



## 2.4 Virtual Tours and immersive technologies

During the pandemic, we have observed an increase of online visits in the range of 10% to 150% (Covid21). In many cases, cultural institutions have included VTs among their online offerings. A Virtual Tour has been defined in several ways (Cho et al 2002, Resta et al 2021). Within this deliverable, we refer to Virtual Tours as interactive simulations of a location, such as a museum or a monument, accessible locally or remotely through a web interface, with hotspots, tags or layers that provide information, accessible using different devices and with different levels of interaction and immersivity (Pescarin et al 2023).

Most of the online VTs platforms are based on customizable templates; some platforms provide 360° panorama only, some allow to move between hotspots and explore a 3D modelled space, and others provide freedom in terms of movements, compatible with HMD. The tours are often augmented with multimedia content. Although the pandemic emergency seems to be over, interactive VTs are still considered of high interest for cultural institutions and for tourists. Moreover, the use of VR is reported to have an impact on on-site travel (Beck et al 2019) and on post-travel experiences (Marasco et al 2018). In a recent survey, it emerged that VTs are fundamental when a site is not accessible, and useful when planning to physically visit it, but they should include other elements: access to details and multimedia content, capacity to explore an architectural space and interact with it, possibility to have social interaction (Resta et al 2021).

For instance, during the pandemic, the Uffizi Galleries and the Museo del Novecento in Milan have developed a significant online presence to offer a virtual museum experience to the public. The Uffizi Galleries have created an extensive catalogue of digital initiatives, including virtual visits, exhibitions, streaming events, video-stories, audio-routes and podcasts. They used the main social networks such as Facebook, Instagram, Twitter and TikTok to involve different target audiences, broadcasting live, publishing posts and in-depth video content and presenting initiatives such as #uffizidamangiare, where chefs and personalities from the food and wine world selected themed works and they created recipes inspired by them. Short art pills were shared on the Instagram channel to raise awareness of the masterpieces, while quizzes were published on the stories to stimulate interaction. The TikTok channel has been used to engage the younger audience with casual and fun videos. The Museo del Novecento in Milan has intensified its presence on social networks, offering virtual visits and presenting works of art on the Instagram channel. They have launched initiatives such as "C@mpus Homeline" and webinars on their site, as well as

involving special guides in the "Keepers Tell" campaign. They have also developed the KitEdu900 for primary schools and the "Call Museum Calls School" to create courses dedicated to children under 10.

The 2019 report "Museums and Social Media. Development and Evolution of user-museum Interaction" highlights that visual content, especially video, is the most popular on museum social media and virtual tours should take this into consideration. Didactic posts, posts on places and territorial contexts of museums, and educational posts obtain greater public involvement. Also, user-generated content is highly valued and shared by official museum pages. The digital communication of museums must translate and simplify complex themes, democratizing art and creating communication between equals. Digital technologies offer a different fruition experience, decontextualizing the works of art in a virtual space. The guidelines for an excellent digital strategy include listening, observing, updating on news and adapting communication to different social media. New skills and professions are required such as social media and Digital Marketing Manager, Digital Curator, Web Developer and Graphic Designer. Collaboration between influencers such as Chiara Ferragni and cultural institutions such as the Uffizi Galleries can lead young people to approach cultural heritage. The "Artyouready?" of MiBACT involved the public in sharing photos of Italian museums and cultural places before the lockdown, promoting the beauty of cultural heritage in the context of the COVID-19 emergency.

A more extended concept of virtual tours, making use of virtual reality and augmented reality technologies, is also leading to a new concept of museums and exhibition spaces. Museums are adapting to new technologies by digitizing themselves and offering virtual visits, allowing people to access works of art even from a distance. At the same time, the physical spaces of museums can host engaging and innovative virtual works. Art has always sought new forms of expression and transformation, and exhibition spaces evolve accordingly.

The evolution of art has been influenced by the tools available throughout history. From the working of clay to the use of colours such as red-purple, up to the drawing techniques assisted by tools such as compasses and squares in the Renaissance. In the 20th century, technical reproducibility led to a new artistic conception, with the serial repetition of subjects and the growing importance of the creative idea over form.

The introduction of technologies has led to interesting results, such as the Van Gogh immersive experience, where moving works are projected onto large walls, allowing viewers to immerse themselves in the paintings. Art continuously adapts to evolutions and must be dynamic. Technology is redefining museums and exhibition spaces, enabling new forms of



interaction and involvement with art. The tools and modes of expression change, but art continues to be a manifestation of the culture of its time.

Examples.

Museums have adapted to new art forms, moving from an artwork-centric approach to creating engaging experiences for audiences. Virtual worlds and museums do not replace physical museums but complement them by offering accessibility and a multimedia dimension. For example, the digital reconstructions of the Acropolis of Athens allow you to virtually visit Greek architecture, overcoming spatial and temporal limitations.

These new museum forms seek a deeper involvement of visitors, creating immersive experiences involving different sensory activities. Virtual and augmented reality have changed the way viewers interact with works of art, making them vital entities that communicate and manifest themselves about the visitor. The virtual work needs the viewer to exist, and personalization becomes important, allowing visitors to make changes and to have an active role in the use of the work.

Even in virtual exhibition spaces, if designed in this perspective, visitors can take control of the visit, deciding the path to follow. However, it is important to underline that virtual restitution cannot replace the direct experience of the masterpieces. Technology serves to support the work, but art manifests itself in the form of virtual reality.

There is recently also a debate about virtual tours and virtual reality installations as forms of arts per sé. Most think that technologies should be only tools to support culture, and the main objective should be to bring people closer to art and its various expressions, making art accessible from anywhere and breaking down economic barriers. Nevertheless, artists are also using these technologies, with virtual experiences that could be seen also from an artistic perspective, as digital born products.

### **Cappella Pignatelli: an immersive virtual tour (Università degli Studi Suor Orsola)**

Another experience implemented by Università degli Studi Suor Orsola Benicnasa is an intervention on Pignatelli Chapel. It is a historic building in the city of Naples owned by the "University, which has recently become part of a program for the development of new strategies for the enhancement and communication of cultural heritage called REMIAM (Network of Intelligent Museums with Advanced Multimedia <https://remiam.conform.it/>).

REMIAM aims to increase cultural accessibility by creating a system of museums, acting synergistically and based on joint planning that adopts unified intervention policies to valorize and promote the territory and heritage.

The University has developed inside Cappella Pignatelli the multimodal visit experience INSITE, which accompanies visitors along a fruition path that offers extra-museum insights through thematic historical-artistic itineraries viewable directly from the building.

The initial stages of the project involved mapping the Chapel and creating five technology stations, each designed and organised to handle different content and convey it through multiple sensory levels.

The arrangement of the stations within the Chapel went along with its floor plan and the content it offers users (Fig. 24).

The first station (Fig. 25) presents a three-dimensional sound experience, accessible with wireless headphones that convey identical narratives. At the same time, the directionality of the audio is different, suggesting to the user how to move within the Chapel and interact with its parts. This way, realising an 'obligatory' fruition path was possible, although the user is convinced to move in total autonomy while listening to the soundtrack.

The second station (Fig. 26) was designed to offer an immersive experience through an Oculus visor: the multimedia content was made with the technique of cinematic virtual reality, with the possibility of movement at 320°; it shows a short film whose objective is to connect the Chapel with the monastic citadel of the Suor Orsola Benincasa.

These two stations were placed on the ground floor of the building because the distribution of the stations fits the morphology of the actual rooms and the possibility of movement within them.

On the second level are the other three stations, which cover all the spaces on the second floor to create continuity in exploring the Chapel.

The third station (Fig. 27) is in the chancel (an elevated walk-through area connecting the ground floor space with the rooms on the first). This location was chosen because it allows better visibility of the highest parts of the building. Therefore, it was fine for visualising the detail elements. Here, through an augmented reality viewing application downloaded to tablets, users can see clearly and sharply all the upper parts of the building, taking advantage of the privileged position of the chancel, which is almost perpendicular to the dome, whose images were captured in high resolution and modelled by modifying the space in 3D.

Next to the chancel, in the room known as the Ogive, is the fourth station (fig. 28), which offers the visitor a moment of insight and interaction with the works of art in the Chapel, which have been scanned in 3D and transformed into virtual models. The visitor can interact with these models, projected on a monitor, through a gesture-based device, capable of reading hand gestures and associating them with commands to rotate and zoom the displayed 3D models, thus allowing the user to inspect them from all points of view.

The last station is also located in the Hall of the Ogive (Fig. 29): It is an interactive touch table that allows users to explore some historical-artistic itineraries remotely: itineraries are selected through the table but are displayed through images, texts and maps on the walls of the room.



Figure 24



Figure 25



Figure 26



Figure 27



Figure 28





Figure 29

The comparison between physical museums and virtual museums is complex because they may represent two complementary entities but with significant differences. While virtual tours can allow to reach otherwise inaccessible places, it is difficult to replicate the same emotions and sensations that one experiences when looking at a live work of art. Although museums try to offer an immersive experience, Augmented Reality seems to be successful in overcoming the limits imposed by the physical nature of the works. Nevertheless, there are many examples of such immersive experiences. An example is "Van Gogh Alive", a multimedia project that allows you to learn about the life and work of Van Gogh through an immersive experience. Other immersive exhibitions in Italy include artists such as Caravaggio, Klimt, Dali and Giotto. While these exhibits offer an immersive impact, some people question whether the spectacularization of the artwork can replace the original work, which has unique characteristics such as colour and brushstroke. However, these initiatives bring more people closer to art and offer static museums the possibility to incorporate movement, dynamism and interactivity. Some projects, such as those at teamLab in Japan, use light, sound and motion sensors to create unique, interactive experiences that blur the lines between people and create new relationships.

The use of devices such as sensitive tables, sensitive walls and sensitive floors is common in the context of Digital Cultural Heritage (DCH). There are many immersive art experiences around the world, such as the Atelier des Lumières in France and other exhibitions in Zurich, London, Toronto, Washington D.C. and Helsinki. In Italy, in Mestre, there is "M9", the largest multimedia museum in Europe that tells the story of the Italian twentieth century.

Virtual tours offer free access to the collections of museums around the world, such as MoMA, the Uffizi Galleries, the British Museum and many others. Some tours allow you to

make real virtual visits, creating a 360° immersive experience. Google Arts & Culture also offers high-resolution virtual tours using Street View technology.

Art and technology come together to create new forms of learning, interacting with artworks, and memorable experiences. Art galleries and museums try to communicate their heritage in new ways, using gamification techniques. This involvement through play makes the cultural experience more attractive and stimulating. Applications have been developed, such as "Nexto" in Berlin, which stimulate the search for monuments in the city to level up and access new challenges. Digital art forms that blend art, science and technology are developing all over the world, such as in the Whitney Museums in New York, the Saatchi Gallery in London and the Nxt Museum in Amsterdam. In 2016, the Ministry of Cultural Heritage, along with the municipalities of Milan and Florence, sponsored the exhibition "Uffizi Virtual Experience" in Milan, offering an interactive experience with high-resolution digitalized artworks from the Uffizi Gallery in Florence. In the new visitor experience, there is a shift in perspective where connection and evolving experiences are essential. Art goes beyond itself, engaging all senses and creating an empathetic connection. Museums have become places of collective participation and sharing, but they must also provide authentic experiences and cultural insights.

These applications are influencing the art world, offering new possibilities for use and involvement. However, it is important to maintain the goal of bringing people closer to art and enhancing art itself, using technologies as support tools for culture.

Companies that offer solutions for digitization and engagement in museums are increasing, offering tools such as interactive virtual tours, app guides for smartphones, augmented reality on works of art.

The following analysis explores the advancements, challenges, and opportunities of virtual tours in the context of museums and art collections.

1. **Technological Evolution of Virtual Tours:** Virtual tours have significantly evolved over the years due to technological advancements. From simple 360-degree panoramic images, the transition has been made to virtual and augmented reality, offering an even more realistic and engaging experience. High-resolution cameras, drones, and 3D scanning tools have enabled the creation of detailed and high-quality virtual tours.
2. **Accessibility and Global Enjoyment:** One of the major advantages of virtual tours is accessibility. People can explore cultural assets from anywhere in the world, overcoming geographical limitations and travel costs.
3. **Immersive and Engaging Experience:** Virtual tours offer an immersive experience that goes beyond merely observing cultural works. Users can interact with the virtual environment, zoom in on details of artworks, access related multimedia content, and even



participate in virtual guided tours. This creates deeper engagement and a more profound understanding of cultural assets.

4. Enrichment of Content: Virtual tours allow cultural content to be enriched with additional information, such as audio descriptions, explanatory texts, videos, and related images. These additional elements provide historical context, artistic insights, and other information that enhances the overall experience. Moreover, virtual tours can include links to external resources, such as academic publications, interviews, and educational materials, further expanding visitors' knowledge.

5. Engagement and Social Interaction: Virtual tours have opened up new opportunities for engagement and social interaction. Users can share their experiences, opinions, and discoveries on social media, creating a virtual community of culture enthusiasts.

6. Lastly, virtual tours have created new creative possibilities for artists and curators. They can experiment with artwork presentation, create personalized narratives, and offer additional content that enriches the overall experience. This broadens physical boundaries, reaching a wider audience and allowing engagement even for those who might not be able to attend an on-site visit.

In the last year after the pandemic, the traditional concept of a "visit" has transformed, leading to a travel experience where interaction and modifications are possible. This shift has changed the role from passive observer to active participant. Experiencing artwork no longer entails mere observation but enables complete immersion and living within it. In potential future developments of museum, users are expected to become more involved in digital narratives, connected with one another, sharing impressions, interpretations, and experiences.

The next section is dedicated to an overview of tools for the creation of panoramas and virtual tours.

### 360 panorama creation tools.

From a perspective of software tools for the production and management of 360 tours, the market offers several alternatives. In particular, the following options stand out:

**Matterport** stands out for its advanced 3D scanning technology. By using specialized cameras and advanced processing algorithms, Matterport allows for the creation of highly realistic virtual tours. The accuracy and quality of scans offer viewers an engaging experience, enabling them to explore virtual environments realistically. Furthermore, Matterport offers a wide range of customization and integration features to tailor virtual tours to specific user needs.

**Roundme** distinguishes itself with its intuitive and user-friendly interface. Providing a seamless experience, users can easily create virtual tours without the need for advanced technical skills. Roundme also offers a variety of customization tools to enrich the tour

experience, allowing users to add points of interest, captions, and audio. These additional features contribute to making the virtual tour engaging and informative for viewers.

**3DVista** stands out for its extensive range of customization features. Users can adapt layouts, colors, transition effects, and navigation elements to create a unique and engaging virtual tour experience. Moreover, 3DVista supports virtual reality (VR) viewing, allowing viewers to fully immerse themselves in the virtual environment. This feature enhances engagement even further by providing a realistic and immersive perspective.

**Cupix** offers an automatic scanning solution that greatly simplifies the creation of virtual tours. By utilizing artificial intelligence algorithms and computer vision, Cupix enables quick creation of virtual tours, converting images into a navigable 3D environment. This feature is particularly useful for those who want to rapidly create a virtual tour without manually capturing footage. Additionally, Cupix provides advanced analysis and measurement functionalities for commercial and design applications.

**SeekBeak** offers a wide range of customization options for creating unique virtual tours. Users can customize the tour's appearance, add interactive elements like hotspots and points of interest, and integrate multimedia content such as images, videos, or audio. This flexibility allows users to create engaging and content-rich experiences. SeekBeak also supports the creation of multilingual virtual tours, enabling users to reach a global audience and provide personalized experiences in different languages.

### Virtual tours authoring tools.

There are several software tools available for the design and production of virtual tours, each offering common basic features as well as a variety of features that can make them more or less interesting, depending on the user's needs. Two are those mostly used by CHANGES Spoke 4 partners: Kuula and Pano2VR.

**Kuula.** Kuula is a powerful online software tool that allows users to create and share interactive virtual tours [kuula.co](<https://kuula.co/>). Kuula's Features include: 1. Virtual Tour Creation: With Kuula, you can upload your panoramic images or photos and organize them to create engaging tours. For instance, if you're a real estate agent, you can create a virtual tour of a house for sale, showcasing every room and angle. 2. Appearance Customization: Kuula offers various customization options for the look of your virtual tours. You can choose from different navigation styles, such as guided tours or free movement, to tailor the experience to your desired goal. 3. Interactive Points of Interest: With Kuula, you can add interactive points of interest to your panoramic images. For example, if you're creating a virtual tour of a city, you can insert points of interest like monuments, museums, or restaurants and provide additional information about them. 4. Labels and Descriptions: You can enrich your panoramic images with informative labels and textual descriptions. For

instance, if you're creating a virtual tour of a national park, you can add labels that display the name of a specific plant or interesting information about the location. 5. Sharing and Embedding: Once you've created your virtual tour with Kuula, you can easily share it with others. You can send a direct link to your clients or embed the tour on your website or blog to allow a broader audience to explore the places you've created. Strengths of Kuula include the fact that it is: 1. User-Friendly, allowing anyone to create virtual tours simply and quickly, even without technical experience. 2. Engaging Interactivity, such as points of interest and labels, provide an engaging experience for visitors. 3. Broad Sharing across various platforms. On the other side it has some Weaknesses as requiring a paid subscription.

**Pano2VR:** Pano2VR is also a powerful software that allows users to create interactive virtual tours using panoramic photos. This tool makes it easy to transform panoramic images into immersive and engaging experiences: [ggnome.com/pano2vr] (<https://ggnome.com/pano2vr>). Pano2VR's Features include: 1. Virtual Tour Creation: (import of panoramic photos and their organization into a virtual tour, adding transition points between photos); 2. Advanced Interactivity to enhance the virtual tour (features to incorporate navigation buttons, hotspots, interactive menus, and even embedded videos to provide additional information and engage visitors); 3. Appearance Customization choosing different navigation styles, adjusting image lighting and contrast, and customizing colors and fonts in the interface; 4. Multimedia Integration; 5. Multi-Platform Publishing tools and editing possibilities of tour as HTML5 files. Strengths of Pano2VR include the advanced functionality, Intuitive Interface and Multi-Platform Support. Nevertheless, some Weaknesses include the fact that the learning curve might be steep, the cost of the license should be considered and there is little flexibility in terms of data integration. Both Pano2VR and Kuula offer powerful features for creating virtual tours and could be fruitfully adopted by non-expert users, such as in the case of cultural institutions. The choice between the two will depend on specific project requirements and the desired level of control and interactivity. Nevertheless an ad hoc open-source solution with templates could be a better solution for the CHANGES project.

## 2.5 Technologies for storytelling, social inclusion and emotion detection

Emotions have been acknowledged as a primary component of the experience of cultural heritage, and of art in particular, for centuries; recently, their role in art has been demonstrated through physiological experiments showing how correlates of emotions, such as brain response and face expressions, are affected by the experience of art (Van Dongen, Van Strien, & Dijkstra, 2016). In addition to their role in defining the way people experience artistic expression (Schindler et al., 2017), from paintings and musical works to movies and

novels, emotions also provide a universal language through which people convey their experience of art, well beyond words. In this sense, emotions can provide a suitable means for connecting people belonging to different groups, intended as culture, age, education, and different sensory characteristics.

In the SPICE EU project (Social cohesion, Participation, and Inclusion through Cultural Engagement, 2020-2023), emotions have been used as a pivotal element of self-expression of museum visitors in relation to works of art, with the goal of promoting a universal, non-textual sharing of experiences between individuals and groups, according to the paradigm of Citizen Curation (Bruni et al 2020, Daga et al 2022). Citizen curation reverses the traditional paradigm of curation, where art interpretation is exclusively entrusted to curators and art historians and critics: citizens are put at the center of the interpretation process, thanks to curation methods which prompt personal responses to art, and promote their sharing across people and communities (Bruni et al., 2020; Daga et al., 2022). In SPICE, citizen curation methods – such as creating stories from artworks and attaching affecting affective annotations to them – are supported by a socio-technical infrastructure which allows museum visitors to create and share their own interpretation of artworks, and to react to other people's interpretations.

In the SPICE project, the use of reasoning tools to generate diversity-seeking, inclusive affective recommendations of artworks and stories has been tested on the collection of the Gallery of Modern Art in Turin, with the goal of breaking the filter bubble effect and nudging the users' attitude towards different interpretations of cultural content. Using DEGARI 2.0 (Dynamic Emotion Generator And Reclassifier (Lieto, Pozzato, Zoia, Patti, & Damiano, 2021)), an explainable, affective-based, art recommender relying on the commonsense reasoning framework TCL and exploiting an ontological model of Plutchik's theory of emotions, the GAMGame app classifies and suggests to museum users artworks and stories that evoke not only the same emotions as the already experienced or preferred artworks but also novel items (artworks and stories) characterized by different emotional stances. The evaluations conducted with the help of the d/Deaf users in cooperation with the Turin Institute for the Deaf, have confirmed the potential of this approach in bridging the interpretations of art provided by of different individuals and communities (Lieto, Pozzato, Striani, Zoia, & Damiano, 2022, Lieto, Striani, Gena, Dolza, Marras, Pozzato, & Damiano 2023)

## 2.6 Game – Gaming – Gamification Design

Games, and in particular Serious Games (i.e., those games whose main objective is not entertainment but rather an educational objective), are tools that have been recognized for years now for their immense innovative and engagement value relative to professional

training, education and transmission of knowledge and informational content, as well as to the enhancement and appreciation of cultural heritage.

Creating a game that can emotionally engage players and achieve a profound impact on their knowledge and habits is not an easy task. The design of games, as well as gamified activities, is a complex process characterized by a highly multidisciplinary nature. Especially in the context of games with a strong narrative component, which are recognized as those most capable of emotionally engaging players and increasing their level of immersion, the challenges related to design are multiple and delicate. Suffice it to say that those tasked with designing the narrative (both in the sense of narrative plot and dialogue and text) often possess little or insufficient computer skills, making it difficult to interact with the tools and pipelines typical of game development.

The CNR ITD has for these reasons designed and developed a tool that addresses precisely these needs. The main design idea is to enhance the writing process by allowing editors to focus on the important elements of story writing while remaining in a context of continuous integration but eliminating the technical and programming skills often required. Using this tool, editors and game designers can create and manage dialogues on a simple visual platform, making new changes directly to the game (even after the game is distributed) without having to code the dialogues themselves or use specific technical file types. Moreover, this type of feature abstraction further eases another of the problems that often plague the design process of the narrative component: localization into different languages. Using the developed tool, translators can work on the localizations in a manner parallel to and independent of the dialogue definition by the editors, gaining the ability to work on the narrative trees as they are completed., and leaving the complexity of synchronization and distribution of work in the hands of the system.

Specifically, the tool developed includes three different components: a web platform that acts as a front-end for writing and organizing dialogues and localizations, a Unity plugin that allows integration directly into the game implementation engine, and a server that is responsible for storing data, performing authentications, verifying data integrity, and synchronizing and distributing the work done by the designers.

Find

Name	NPC Name	Dialog #	Version	Edit	Localizations
Tutorial1 - Abitante Villaggio	Abitante del Villaggio	1	9		
Tutorial2 - Bambina	Bambina	1	4		
Tutorial3 - Bambino	Bambino	1	7		
Tutorial4 - Badessa	Badessa	1	13		
Tutorial5 - Donna Villaggio	Donna del villaggio	1	11		
Tutorial6 - Suora Amanuense	Suora Amanuense	1	13		
Tutorial7 - Magistra	Magistra	1	18		
Tutorial8 - Goscelin	Goscelin	1	13		
Tutorial9 - Contadino	Contadino	1	7		
Tutorial10 - Sorella Sarah	Sorella Sarah	1	22		
T1 - M1 - D1 - Goscelin	Goscelin	2	50		
T1 - M1 - D2 - Margareth	Sorella Margaret	1	71		
T1 - M1 - D3 - Badessa	Badessa	2	47		
T1 - M1 - D4 - Wolfstan	Padre Wolfstan	1	28		

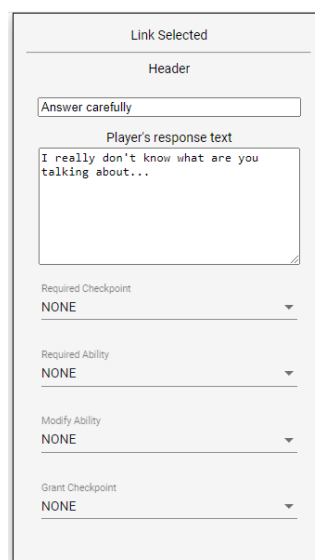
Add a new Dialogue

[Download the Italian version of the dialogues](#) | [Download the English version of the dialogues](#)

Specifically, the web platform allows users to log in from different locations and devices without requiring the installation of additional software or applications. Once logged in with username and password, the user is presented with the main page where he or she can view the list of dialogues already entered, create a new dialogue, and download all the dialogues in the project (in the various languages in which localization has been carried out) in an easy-to-read, offline-friendly text format. Within the system, each dialog has several attributes (e.g., dialog name, NPC name, dialog version number, etc.) that can be used both to quickly navigate and recognize dialogs and to sort them. In addition, A search field above the dialog list allows you to filter the results and quickly identify the dialog you want to work on. On this screen, you can also view the localization status of the chosen dialogue (how many localizations are planned, along with the processing status of each localization). The dialog creation/editing screen is realized through the use of an oriented graph in which nodes represent NPC lines and edges represent player lines. In the case where a node has more than one child, the player will be shown the various response options and, based on his or her choice, the dialog will follow the corresponding path. Both nodes and edges have two key attributes: an attribute called "header," which represents a brief description of the content of the dialogue, and an attribute called "dialogue text," which includes the text of the line that will be shown in the game. The header attribute is used to label nodes and edges within the graph, for ease of reading, and as a preview of the response within the relevant dialogue option in the game.



While nodes (i.e., the elements that describe NPC lines) are characterized solely by the two attributes header and dialogue text, edges (the elements that describe player responses) have additional attributes and metadata useful for defining constraints (e.g., the requirements tied to having reached a particular checkpoint or having acquired a particular skill), functionality (e.g., the acquisition of a skill or the reaching of a particular checkpoint), and properties within the dialogue. The specific values these metadata can take are specified along with the design project and can vary dynamically, making the system versatile and adaptable to different games.



Link Selected

Header

Answer carefully

Player's response text

I really don't know what are you talking about...

Required Checkpoint  
NONE

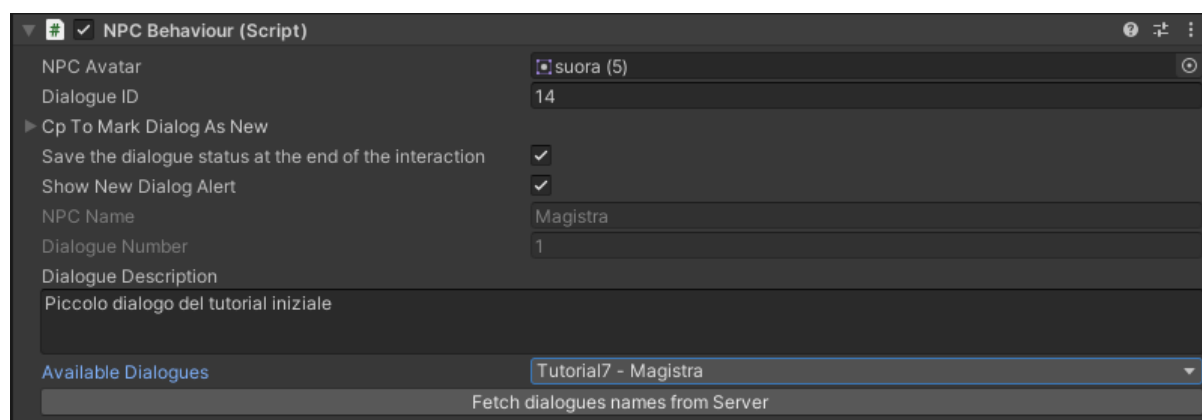
Required Ability  
NONE

Modify Ability  
NONE

Grant Checkpoint  
NONE

Regarding the integration with development engines, and in particular, with Unity, the plugin provided together with the tool is composed of a component dedicated to dialog visualization, some C# scripts dedicated to deserialization and interpretation of dialog data, and a component ready to be assigned to NPCs provided with dialogs. The latter component makes it possible to perform retrieval of the list of dialogs available on the Server and quickly and easily select the correct dialog to be associated with the NPC. Once the dialog is selected, the component automatically updates the relevant fields, synchronizing the data in a simple and transparent way.

The Plugin also contains a component for retrieving and checking the version of the internal dialog database. If this component is added to the initial scene of the game, it is possible to check at each startup whether the version present in the internal database of the app is up to date with the one present on the Server, and if not, update it automatically by downloading the new data.



## 2.7 Educational Immersive Platform for the metaverse

Another technology that the consortium can make profit from is telepresence. Partners such as CNR ISPC has specific research dedicated to the creation of personalized virtual spaces for immersive educational platforms, such as LearnBright (<https://www2.learnbrite.com/>), with personalized avatars and digital spaces, video streaming (including multi-video streaming) with document sharing and reactive objects, useful for online immersive and collaborative teaching or guided tours.

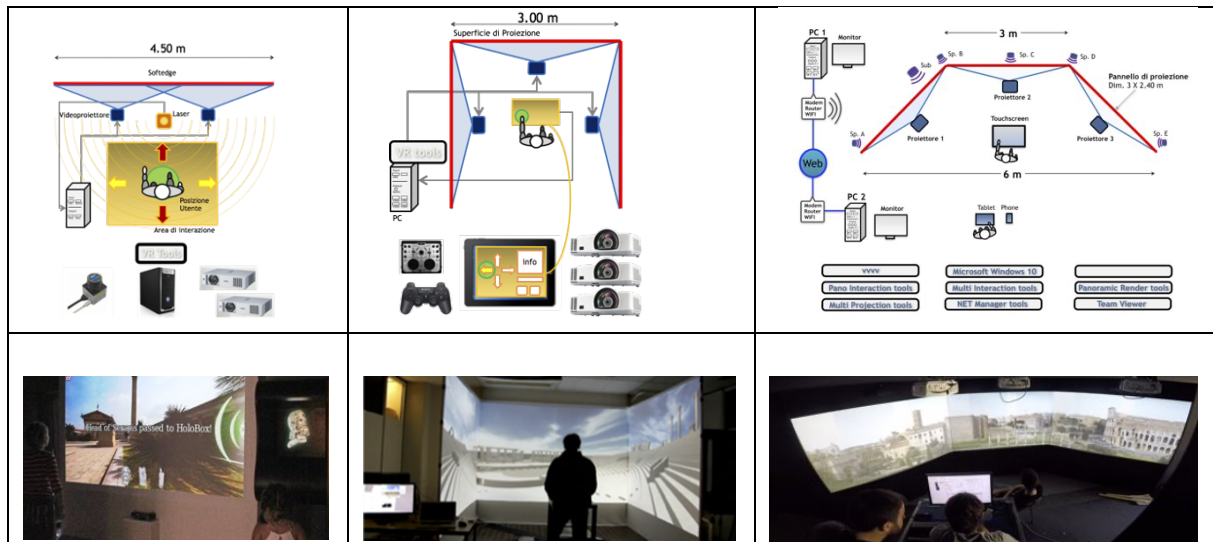


Figure 30 - A learnbright personalised session with a guided experience inside the Brancacci Chapel set-up (CNR ISPC)

## 2.8 Indoor immersive setups

In the last years, museums have demonstrated more and more their interest in immersive setups. Projected large environments, in fact, enable the participation of different visitors at the same time, while the experience could be designed as linear and strongly based on

storytelling or fully interactive. CNR ISPC is fully involved in the research of optimal solutions for immersive setups, although it has identified already three potential set-ups easier to integrated and installed in museums: a) 1 screen based projection, b) 3 screen cave interactive installation and c) immersive theater.



The set-ups are prototyped and simulated before the installation, thanks to vvvv visual live programming environment (<https://visualprogramming.net/>)

## 2.10 Interactive devices for museums (Tiche demonstrator "FURIOSE Interazioni")

"Furiose Interazioni" demonstrator is a project involving several partners belonging to the TICHE consortium, including the "Università degli Studi Suor Orsola Benincasa". It aims to propose innovative and immersive didactic methods for digitally enhancing Ludovico Ariosto's work in the Mauriziano's building in Reggio Emilia. In this place, the poet was born. The demonstrators included several installations almost completed as a UNITY-based new interactive UX to access literature works through touch-based interfaces (multitouch interactive wall), 3D displays where users interact via physical IoT-connected objects, and an immersive experience utilising VR visors. Added is a guided cinematic virtual reality tour of the newly restored 16th-century frescoes in Ariosto's birth rooms.



Finanziato  
dall'Unione europea  
NextGenerationEU



Ministero  
dell'Università  
e della Ricerca



Italiadomani  
PIANO NAZIONALE  
DI RIPRESA E RESILIENZA

CHANGES

CULTURAL HERITAGE ACTIVE INNOVATION FOR NEX-GEN SUSTAINABLE SOCIETY  
EXTENDED PARTNERSHIP



Fondazione CHANGES - Cultural Heritage Active Innovation for Sustainable Society  
Piazzale Aldo Moro, 5 00185 Roma | CF: 96543050585 | [fondazione.changes@uniroma1.it](mailto:fondazione.changes@uniroma1.it)

### 3. State of the art analysis of solutions applied the museum categories

#### Cat.1: Archaeological Museums (Egyptian Museum Turin)

Archaeological Museums are in most cases characterized by three main aspects, potentially impacting the choice of a technological solution:

- a. artifacts are coming from excavations spatially far away (from the location of the museum),
- b. items are exhibited far away/ outside their original context (i.e. a statue originally belonging to a temple or a vase to a tomb),
- c. objects are often in fragmentary conditions, making them and their functions difficult to interpret.

Main needs and requirements regard therefore the capability of the technologies to re-contextualise the items, to reconstruct the original context (environment, monument, etc), to clarify their function and meaning. A further need regards the capabilities of visitors to fill the gap between their knowledge / experience and the cognitive horizon hidden behind the collection. Moreover, visits involving groups of people should be considered as a priority, leaving to pre or post experiences single users' applications.

Examples of applications responding to these needs include very diverse technological solutions. We report some of these examples below.

**The virtual museum of Ancient via Flaminia (2006)** and its second release (2014) was an application dedicated to the 3d reconstructed environment of Rome in the 1<sup>st</sup>/2<sup>nd</sup> century and specifically the area of the Villa of Livia. It was, in its first release, a multiuser natural interaction application where 4 visitors, could sit at the archaeological museum (Diocletian thermal baths, national roman museum), explore the 3d reconstruction using a joystick, while the rest of the visitors of the museum could assist to the experience using stereo glasses and watching a large screen. In its second version, all interactive devices have been eliminated and substituted with natural interaction: a single user was tracked by a Kinect sensor, transforming his/her movements into interactive behaviours, movements and selections of content in the 3d world (fig. below) (Forte et al 2006, Pietroni et al 2015)

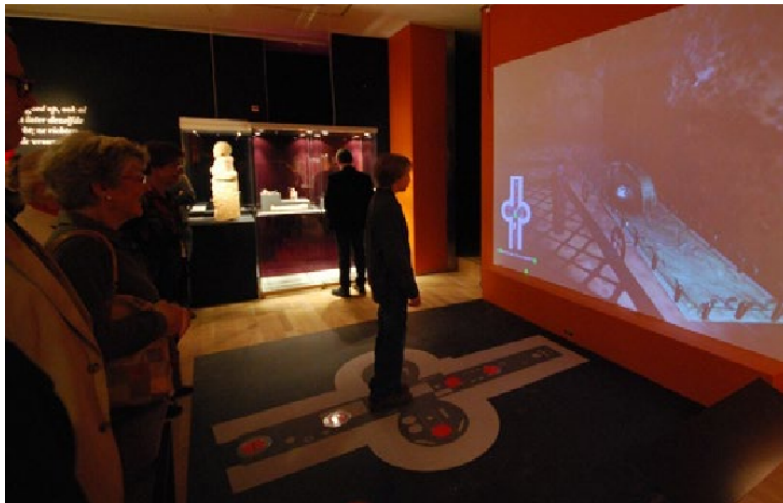




**Admodum** (2014) has been a VR application for 2 users, based on natural interaction (sensor KINECT) and a serious game approach, developed for the Keys to Rome exhibition and the museum of the Imperial forum in Rome. Visitors could use their bodies to explore 3D environments and visualise the objects found in the museum exhibition, but in their original digitally reconstructed context. The original concept is based on the idea of dividing the paradigm of exploration in two different types: (a) the 3D first-person real-time exploration of reconstructed scenarios (reconstructed contexts) and (b) the interactive manipulation of single objects that need to be further explored. The two types of interaction are connected with different gestures and different learning and visual goals (figure below) (Fanini et al 2015).



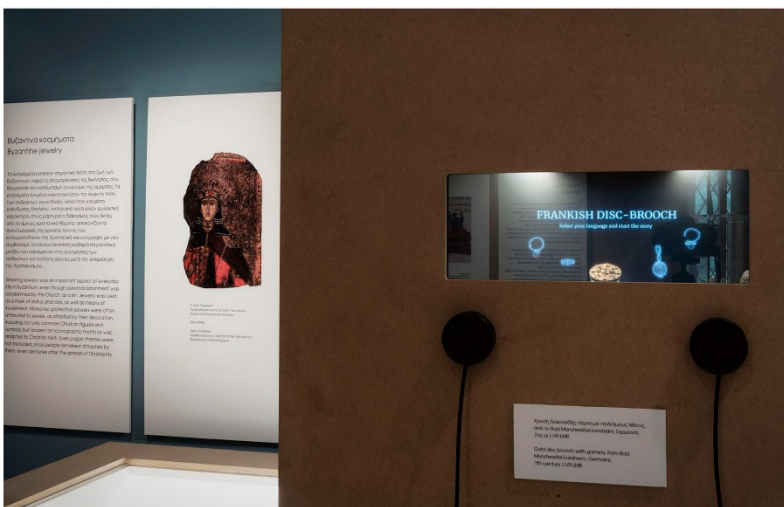




tomb (Pietroni et al 2012). Also in this case the set-up was made of a projector and a Kinect sensor that was transforming the movement of the user into interaction in the 3d space (figure on the left).



Another and different approach has been followed by the **Cemec project (2019)** with the design and development of an holographic museum displays where visitors could see the museum objects inside a case with a projection of a story and reconstruction directly on them (Pietroni et al 2019, figure on the left).





Redrask (2020) is an Online 3D puzzle aimed at re-contextualization and gamification of drawings of Beit el Wali nubian temple. The web-app is being developed for the Egyptian museum, within B.A.C.K. TO T.H.E. F.U.T.U.R.E project, in collaboration with DAD (Dept. of Architecture and Design) of the Turin Polytechnic (figure left) [http://www.backtothefuture.polito.it/TemplePuzzle3D\\_en.html](http://www.backtothefuture.polito.it/TemplePuzzle3D_en.html)

In the next section we analyse the **Egyptian Museum of Turin** as a reference example and we discuss potential technological solutions best suited for a new exhibition area that the museum will open during 2024.

This specific museum has a large and internally articulated space open to a large and heterogeneous public, a high number of objects belonging to different but very far archaeological context, and an outdoor area in the courtyard foreseen as a new exhibition space, accessible publicly and with free entrance. The museum has already a long experience with virtual technologies and low-tech solutions, such as the presence of immersive audiovisual systems, touchscreens displaying the topographies and reconstructions of mummies, online mini games about re-contextualisation of artifacts in the original monuments in Egypt. This museum shares the three above-mentioned needs with many other museums.

For this reason, Virtual Museums, and more in general, **technologies suited to visually re-contextualise, re-construct and story-tell original location, aspect, function and meaning** of an artifact, are particularly indicated. From a research perspective, a **combined use of virtualization techniques, learning approaches and narrative methods** to engage a mixed audience would be highly suggested.

Although there is a vast bibliography and many studies on Virtual Museums (Pescarin 2014), we focus here on works and researches about main relevant goal-oriented approaches of Virtual Technologies:

- 1) Technologies for the virtualization and 3D representation
- 2) Technologies for Learning
- 3) Technologies for storytelling

## 1) Technologies for 3D/Virtualization and Frameworks for the generation of 3D environments.

There are many proposals, especially in more recent years. Technologies vary, but Unity and Unreal Engine are often considered. There are cases of more complex systems that integrate, for example, ontologies (Zidianakis et al. 2021) or content management systems (Milosz et al. 2020). Then there are very technical works that deal specifically with photometry and how to make 3D models (e.g., Skamantzari and Georgopoulos 2016).

There are also relevant works that try to compare various tools, among them "Using 3D modeling and game engine technologies for interactive exploration of cultural heritage: An evaluation of four game engines" (Smith et al. 2019), in relation to Roman archaeological heritage seems to be the most refined.

"3D scanning digital models for virtual museums" is also an interesting work for this topic. Concerning the digitization of museums, it is difficult to find points in common between these works. Every work describes its own project and reports its results, which are often not explored (and are left to future work). However, the most recent works can be a source of inspiration for the development of our own techniques.

## 2) Technologies for Learning and evaluation

Several works focus on the learning aspect in relation to the use of virtualization tools.

The paper "Worth a Thousand Words? The Usefulness of Immersive Virtual Reality for Learning in Cultural Heritage Settings" (Tost and Economou 2009) tries to answer the question: is learning through these tools ameliorative or not? It's also quite cited (a paper from 2009). The most interesting work in this sense is "Can Virtual Museums Motivate Students? Toward a Constructivist Learning Approach" (Katz and Halpern 2015), a study with 500 participants to analyze cognitive involvement.

As mentioned above, few systems are properly evaluated. The paper A survey on developing personalized content services in museums focuses on the recommendation aspect, however it does offer an evaluation framework that could be relevant for us.

In "Achieving effective visitor orientation in European museums. Innovation versus custodial" the correlation between the intent of museums to understand the interest of their public and their actual success is studied. It presents an empirical study of 500 European museums, and the paper could be exploited in order to find inspiration for some of our design choices.

## 3) Technologies for storytelling

In the field of communication, storytelling is considered particularly effective and easy to remember, with the same compactness of the message (Gershon Page 2001, Kosara and

Mackinlay 2013). In cognitive and social psychology, it has been recognized that stories have the function of conveying the values of a culture (Bruner 1991). In media aesthetics, the ability of narratives to engage audiences has been related to the process of identification with characters (Currie 2009, Carroll 2007). In narratology, narrative structures have been studied in order to extract patterns of meaning (motifs, tropes, situations) that recur across genres and cultures (Thompson 1955, Polti 1924, Warburg and Warnke 2000) and media (Campbell 2008).

Cultural heritage has a tight relationship with narrative heritage, understood in its sense of intangible heritage. Cultural objects refer to and often directly display narrative elements: mythological characters and deities (e.g. Ariadne, Horus) events and actions (e.g., leave, fight, donate) objects (e.g., the ball of yarn, the scale) places (e.g., Arcadia, Rome) through symbolic elements recognized as such in the iconographic field (Sartini et al 2023).

The intrinsic narrative component of cultural objects can be exploited by curators to create narratives with which visitors can relate emotionally, accessing through them the objects they refer to. Such stories typically have varying degrees of 'narrativity', ranging from a simple sequential ordering of cultural objects to the construction of a set of chronological and causal relationships between them.

Media studies have highlighted the difference between the narrative content and its realization. The narrative content itself, understood as the semantic representation of the narrative contents and of the relationships (temporal, causal, thematic, etc.) between them, can be conveyed to the public through different media and languages (Bolter and Grusin 1996): the textual format of a biographical file, the visual format of a chronology on an information panel, the video format of a documentary in a thematic room.

Last, but not least, interactive stories and narrative games may be effective formats for the engagement of museum visitors, especially if compatible with the use of the visitors' personal devices, according to the well-known Bring Your Own Device (BYOD) paradigm.

## Story generation frameworks

Given the background described above, it is possible to trace a general framework for the generation of stories in a semi-automatic way. The narrative framework includes three main components: 1. *A representational component*; 2. *A procedural component*; 3. *A procedural component*.

*The representational component* i.e., a formal representation of the notion of story in a standard machine-readable language, whose function is to describe the narrative elements (characters, actions, events, etc.) and the relations over them for use by the software



modules that manipulate the stories (Damiano et al. 2012, Zarri 2013, Lieto and Damiano 2014, Menghini et al. 2021, Damiano et al. 2019). For example, the Narrative Ontology developed in the European project "Social cohesion Participation and Inclusion through Cultural Engagement" - SPICE (available at <https://w3id.org/spice/SON/NO/>) allows describing both the narrative relationships "within" a cultural entity (e.g., the representation of a certain story or character) and the narrative relationships over a set of cultural entities, used to define narratives created by the curators.

2) *The procedural component* is, for instance, the story engine, which takes as input a set of narrative elements and arranges them step by step into a linear story, which can be forwarded to a realization platform capable of producing a directly usable format (Gervas et al 2013, Damiano et al. 2021). A survey of story editing and generation environments can be found in Shibolet and Lombardo 2023.

3) *The collection of story patterns* is a set of predefined story templates whose function is to simplify and make the creation of stories more effective. Extracting and cataloging patterns in stories and drama is rooted in a long tradition, ranging from ethnology (Thompson 1955) and classical studies (Highet 1949) to semiotics (Propp) and screenwriting (Politi 1924, Campbell 2008). While the representational and procedural components are at least partly independent of the application domain, narrative models require the intervention of domain experts (curators, art historians, media writing experts) and should be adapted to the characteristics and objectives of the specific domain (Lombardo et al. 2019, Damiano et al. 2019).

## Cat.2: Parks (Literary Parks Grazia Deledda, Carlo Levi)

Parks are natural environments with historical, archaeological or naturalistic elements. In some cases it's the environment itself that has been the background or the scenario of events, stories or the life of a writer, as in the case of Aliano or Galtelli parks, hiding much of the Intangible Heritage. These types of museums can not host technologies as in the other indoor cases. The type of experience a visitor can have in a park is different: the personal and social dimension are interconnected, all senses are involved, being focused on visual, auditory, olfactory and tactile stimuli. Visitors move following paths and itineraries, from a visual marker to a visual marker. Physical elements can be placed and used as bridges to technologies and the other way round. The main approach adopted in these contexts is the so called BYOD (Bring Your Own Device), since the smartphone is the only device that typically each visitor has during the visit, while any other ICT on site installation should be carefully designed and maintained. Nevertheless, also a mobile application should be carefully planned, to avoid a negative isolation effect, especially with a group of people,

focusing on strategies to increase reflection and to widen the experience. Web-based solutions are mostly suited and appreciated to support the preparation of the visit or the post-visit experience, while audio-guides often based on geo-location services are chosen for their flexibility and capability of involving the hearings only, leaving hands, feet and eyes free to explore. Many parks include a visitor center or a building dedicated to the exhibition of specific collections. In this case, it is possible to design and install on-site applications and more complex systems.

*Archaeological parks* have made use of advanced technological installation, since a long time. In 2004, the archaeological landscape of Aksum was made accessible thanks to a 180 degree interactive 3d exploration and visualisation system, **Vision Station** by Elumens (Bonfigli et al 2004) (fig.left).



*Vision Station and the Aksum archaeological landscape (2004: CNR ITABC)*



*Tiber Valley virtual museum (2014: CNR ITABC)*

A 3D interactive exploration, based on narrative and gaming elements, of the **Appia Archaeological Park** in Rome has been also created by CNR in 2005. The user, with a desktop computer and a joystick, could meet virtual characters during the visit, listening to narrative elements connected to specific locations (Pietroni et al 2005). Some years later, in 2013 a similar approach was followed by the Virtual Museum of the Tiber Valley, developed in Unity and installed inside the Villa Giulia museum; in this case the interaction of the user was based on natural gestures, while three monitors gave three different spatial and historical perspective on the 3d landscape (Pietroni et al 2013) (fig.left).

Examples that include gamified approaches are the **Pleistostation**, game installed at the museum of Casal de' Pazzi in Rome, a Touch interaction point and click 2d game for kids based on the discovery and the comparison between two parallel worlds: the contemporary landscape and that of the Pleistocene period, and **Aquae patavinae VR**: a web-based on line 3d interactive exploration of an archaeological landscape (termae euganee) through gamified mechanics.

A different approach, based on less interaction but on more immersive experience for a group of people has been developed for the **Museo del Paleolitico di Isernia**: a 360



interactive exploration of a paleolitical landscape inside the local museum, made of 3 Monitors, Control Panel, for on-site Indoor use (fig, below)



*Virtual Museum immersive projection of Isernia Paleological museum*

Recently, the ministry of cultural heritage has launched e-Archeo dedicated to 8 archaeological Italian park. A specific section was dedicated to 3D and 360 interactive exploration of the parks, Based on ATON framework; for Outdoor: Links: <https://e-archeo.it/output/#e-archeo3d>

All these applications require the interaction of users (mainly single users) and have been installed in most cases indoor, in the reference museums or visitor centers. There are many different applications that, instead, have been designed for mobile use. We report here an example of such applications.



Mura Vive: Narrative environmental installations, stations equipped with insights through three-dimensional renderings and animations, mobile apps; multimedia and widespread experience; Comune di Padova: <https://www.muravivepadova.it/cosa/cosa.html>.

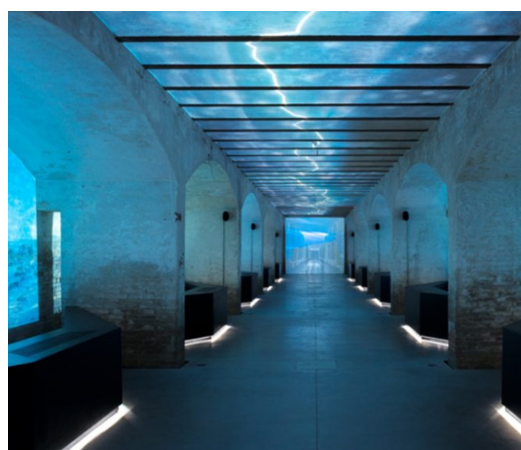
Another example of mobile app dedicated to the visit to an historical center is the app "Cento Città

del Guercino" (<https://centocittadelguercino.unibo.it/>).

GIS-based interactive applications based on ArcGIS Pro is the project dedicated to the harbour of Ravenna (<https://www.darsenaravenna.it/home-tematica-scopri/storymap-folder>).

Regarding *Naturalistic Parks and Gardens*, the national park of Tuscany archipelago has created immersive views of otherwise unreachable points on the islands, with display and visitors showing videos and 3D contents immersively (<https://www.agmultivision.it/2022/06/24/tecnologie-multimediali-ambienti-immersivi-pnat/>). Rossi Park has designed a multimodal and multi-sensory audioguide, interactive and multimedia game accompanied by stories, quizzes, games, augmented reality and videos, and a 3D speaking printed model (<http://www.parcorossi.it/event/vieni-a-scoprire-le-novita-di-parco-rossi-for-all/>).

*Literary parks* are a new type of parks and do not have specific technological solutions, a



*Pascoli Poetry Multimedia Museum*

part from special events with narrative and light shows. On the literature topic, nevertheless, there is **Pascoli Poetry Park** with its multimedia museum made of digital stage sets, video mapping, sound, and word games, setting up a fully immersive experience, sensory and emotional journey for the visitors (<https://parcopoesiapascoli.it/museomultimediale/>) ([video](#)).

Completely on line, on the other side, is “**Take a tour of Cervantes**” project by Google Art with its mixed media ([link](#)), while “Virtual Poetry 360” is based on 360 panorama videos and directional sounds, with voices telling poems ([link](#)).

Other examples of interactive set-ups have been already presented in the previous chapter (Tiche demonstrator “**Furiose Interazioni**”, “indoor immersive set-ups”).

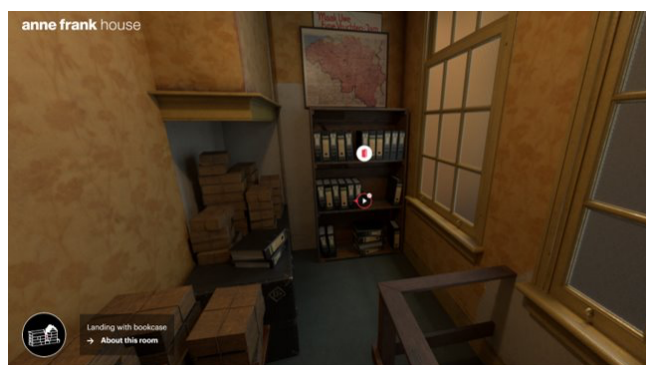
An even more immersive and suggestive experience is the “Virtual Poem Noccc / Nightsss VR experience” for Head Mounted VR Display, an experimental and sensual experiment of poetry, dance and nature and at the same time a poetical walkthrough made of sounds and lights in a garden in virtual reality ([video link](#)).



*the Nightss VR experience*



On the same direction the “Chalk Room” VR experience, by the conceptual artist Laurie Anderson, where users immerse themselves into a large space filled with language, extending the speech and writing of a poem ([link video](#))



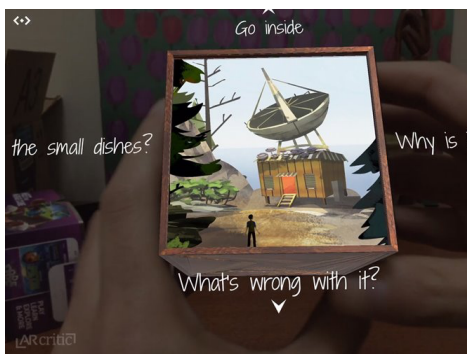
*The Secret Annex*

Dedicated to the preparation of the visit and home entertainment is also “The Secret Annex”, A virtual exploration in Anne Frank house with links to documents, video and audio material, developed using 3D graphics 360 exploration

(<https://www.annefrank.org/en/anne-frank/secret-annex/>).



*We Were Here Together videogame*



*57 North tangible AR game*

Games have been also created to engage players with immersive 3d graphics and intriguing narrative dedicated to landscapes. Some of these games are designed for multiuser experience, such as “We were here together”, a Co-operative Adventure for 2 players who communicate through a walkie talky, while exploring a territory and some buildings. Another interesting game, focused on the spirit of adventure of the players and based on tangible interaction and AR, is “57 North”. It is an AR game for the Merge Cube with an interactive story based on visual elements visible by handling a 3d cube (<https://www.mightycoconut.com/57north/>) ([link video](#)).

There are, to conclude, several examples of guided tours that make use of digital technologies, based on line resources or social media.

An example of particularly involving emotionally audioguide is the app created for Palazzo Milzetti (<https://palazzomilzetti.cultura.gov.it/>)

### Cat.3: Demo-ethnic-anthropological-geology-natural history museums (Capellini Museum, SMA Ferrara, Museo Lombroso)

Many of these museums are not open regularly and rarely have or make use of digital content. Often they lack also of basic captions and panels, while, due to the specialized nature of their collection and to the general weakness of communication tools, they require a guided visit, at least for not-expert visitors.

There are several examples that have been developed for museums of these types. We can categorize them in applications that make use of AR and 3d reconstructions, applications that use also tangible elements such as cards or tangible reproduction, VR immersive experiences focused on the discovery and exploration of reconstructed natural elements and collection, and , finally, games.



3D models and AR applications of paleontological collections:

<https://www.nhm.ac.uk/discover/dippy-the-dinosaur-3d-skull.html>

Arts and Culture Google: [https://artsandculture.google.com/ar-model/GAG\\_J9wcz31GXw](https://artsandculture.google.com/ar-model/GAG_J9wcz31GXw)

The PalaeoGo!! Experience is an 'augmented reality' app tht enables to 'dig deep' and answer educational questions on the fossils at The Etches Collection (<https://www.theetchescollection.org/palaeogo>)



*PalaeoGo!*

**4D Dinosaur Experience** is a deck of Augmented Reality Cards that creates a journey with 3d dinosaurs for the users and that can work also for VR Headset, by Utopia360VR (<https://www.youtube.com/watch?v=T2OxKm7QvjU>)



*4D Dinosaur Experience*



Immersive VR applications:

**Jurassic World 360 video experience** (<https://www.youtube.com/watch?v=93nxeejhPkU>)  
it's a series of 360 videos modelled in Computer Graphics and playable also with google cardboards.

**Hold The World** for Oculus Rift, where a visitor wearing a VR headset can have the unique opportunity to meet Sir David Attenborough at the London's Natural History Museum, and get hands on rare specimens from its world-famous collection, going behind the scenes to explore areas usually closed to the public (<https://youtu.be/nr3l98Omm-0>)



*Hold The World Experience*

**"Journey into the heart of Evolution"** of the Muséum national d'Histoire naturelle (French National Museum of Natural History ) and the Orange Foundation designed a unique immersive virtual reality experience for the audience to explore the tree of the living, iconic species and how they are related to each other (<https://youtu.be/Mp1G5ZFpzJA>)

While at the American Museum of Natural History, a VR applications with HTC Vive was developed as a multiuser interactive experience: **"T. rex: The Ultimate Predator"** exhibit (<https://blog.vive.com/us/htc-vive-partners-american-museum-natural-history-bring-iconic-t-rex-life/>); this VR experience places up to three visitors within a space similar to the Museum's Hall of Saurischian Dinosaurs, where they will work together to help build a T. rex

skeleton bone by bone. Once the full dinosaur is complete, players will witness a realistic T. rex come to life before their eyes.

There is also an interesting approach that includes the use of Games for these types of museums, while the gamification of Geosciences is perceived as a good way to get a new generation engaged. Examples are: VR Jurassic escape ([https://store.steampowered.com/app/1477650/VR Jurassic Escape/](https://store.steampowered.com/app/1477650/VR_Jurassic_Escape/)); the Immersive Geology mod Minecraft (<https://www.curseforge.com/minecraft/mc-mods/immersive-geology/screenshots>); Dinosaur Fossil Hunter Simulator di paleontologia ([https://store.steampowered.com/app/864700/Dinosaur Fossil Hunter Simulatore di paleontologia/](https://store.steampowered.com/app/864700/Dinosaur_Fossil_Hunter_Simulatore_di_paleontologia/)): a video game available on Steam which reproduces the work of a paleontologist in its details, a simulator that shows the interesting aspects of the job), just to mention some of them.

#### Cat.4: Historical Monuments, Palaces and House Museums (Reggia Caserta)

The "Reggia di Caserta" was built starting in 1752 at the behest of Carlo di Borbone (1716-1788). It was a very ambitious project entrusted to the well-known architect Luigi Vanvitelli (1700-1773) to ensure a new Borboni residence and boost the city of Caserta and the surrounding area.

A UNESCO World Heritage Site since 1997, the "Reggia di Caserta" is a museum of significant national interest, endowed with scientific, financial, accounting and administrative autonomy, and is a permanent, non-profit institution that aims to protect, study and enhance the Vanvitellian Complex, consisting of the Royal Palace, the Royal Park, the English Garden, the Carolino Aqueduct and the "Bosco di San Silvestro", which together form part of the Borbonis' "Reali Delizie."

The royal palace (45.000 square meters, 42 m. high, five floors above ground and 1,400 rooms) represents the complex's main attraction: its construction began in 1752. It was completed only twenty years later, thanks to significant funding (4.480.651 ducats, an impressive figure for the time). The interiors had yet to be furnished when the palace was finished in 1773. Therefore, the arrangement of the apartments lasted throughout the first half of the 19th century under the leadership of Carlo Vanvitelli, son of Luigi. After all the work, the Reggia stood out among Europe's most prestigious royal residences, not only because of the exceptional beauty of the building and its prestigious furnishings but also because of its vast and beautiful green spaces. The Royal Park (100 hectares, three linear

kilometers, six monumental fountains, 60 statues), built to Vanvitelli's design, had Italian Renaissance gardens as models. However, solutions adopted at the Palace of Versailles were also introduced to create an impressive and evocative landscape system that included fountains, pools and water features, groves and gardens.

In Caserta, the fountains, arranged along the central axis of the park and organized in a continuous succession, played a central role in the design of the exteriors, to the point that the Carolino Aqueduct (38 km long, 67 towers), a work of hydraulic engineering designed by architect Luigi Vanvitelli and begun in 1753, was built to supply them. The aqueduct begins at the foot of Mount Taburno, where it draws from the Fizzo Springs at 243 meters above sea level. It continues for its entire length, almost always underground, to surface only at specific points via canal bridges. Famous among these is the Valley Bridge, where the conduit crosses the Maddaloni Valley using a structure with three rows of arches, 60 meters high and about 500 meters extended. Complementing the evocative atmosphere of the pools and water features are also the English Garden and the San Silvestro Woods. The Garden (23 hectares, 228 tree species, four historic greenhouses and 24 sculptures) was built at the behest of Queen Maria Carolina on the advice of British minister William Hamilton.

Botanist John Andrew Graefer was hired for its realization, who, together with Carlo Vanvitelli, decided to create a garden of romantic taste full of seemingly wild views, reliefs, waterways and antiquities, many of them from the excavations of Pompei and Ercolano. The "Bosco di San Silvestro" (76 hectares of woods for 26 years a WWF oasis), which stretches behind the Royal Park on the hills of Mount Maiuolo and Mount Briano, destined for agriculture and hunting, was entrusted to WWF in 1993 and became an oasis open to the public.

To enhance these green areas, which are central to the overall design of the entire complex, the museum, with the contribution of the Kainon Foundation, has created a virtual reconstruction of the gardens as they were designed by Luigi Vanvitelli, thus, different from the ones we see today and which were designed by his son Carlo. The reconstruction presented on the exhibition *Fragments of Paradise*, organized at the Royal Palace of Caserta in 2022 (<https://reggiadicaserta.cultura.gov.it/mostra-frammenti-di-paradiso/>) allowed a viewer to walk through the gardens that were never realized virtually.

The success of the exhibition prompted the implementation of the application for a permanent installation and the design of a second interactive exhibition, which took place in 2023 on the occasion of the Vanvitellian Celebrations, for which a multimedia path (a touch screen installation for personalized enjoyment of audio, text and image content) was created, thanks to which the user can learn about Luigi Vanvitelli's activities through the

different phases of the construction of the Royal Palace, the Park and the Carolino Aqueduct (<https://reggiadicaserta.cultura.gov.it/celebrazioni-vanvitelliane/>).

Considering examples of digital applications developed for such historical monuments, we should quote the interesting work done years ago at Versailles, Paris, by Google Art Institute. The project has been an experiment, called "Chaos to Perfection", HTML5 web-based (<http://www.chaostoperfection.com/>; <http://www.versailles3d.com/en>). It takes the visitor on a desktop or mobile tour of Versailles, reconstructed in 3d, from the Grand Canal to the King's bedchamber, including the Orangerie, the Hall of Mirrors and the Colonnade grove. The work is designed as an immersive interactive film.



*Chaos to Perfection*

More recently, in 2018, the same monument has invested in "Versailles VR", an immersive experience that includes over 140 artworks, rebuilt rooms and a detailed audio information guide (<https://www.makemepulse.com/case-study/versailles-vr-the-palace-is-yours/>)



*Versailles VR*



## Cat.5: Art collections (CSAC Parma, Galleria Estensi Modena, NAVIGA UNISOB).

NAVIGA – Mostre Digitali – Università degli Studi Suor Orsola Benincasa

The Università degli Studi Suor Orsola Benincasa has launched a project to digitise and use its art collections by developing a platform that allows users to visit exhibition environments via the web. The Mostre Digitali platform allows connected users to visit five exhibitions, moving 360° within a digital exhibition environment, where navigation is continuous and similar to the path one might take while walking in physical space. The digitised content has also been integrated with other multimedia supports, such as audio guides, ambient music, access to video and sound web content, and co-presence on the work (in case of restoration or views) of the overlay with the pre-restoration work.

The platform is structured on two software layers: a site based on the CMS, from which to access the various exhibitions, easily manageable even by different teams, as it is, in fact, a standard; a Unity web layer that allows (activating automatically when the exhibition is chosen) to enter and move freely in the digital space.

From the homepage of Mostre Digitali (<https://mostredigitali.unisob.na.it/>), the user can choose which of the five exhibitions to visit by clicking on the title, at which point the platform redirects him/her to the 'Exhibition Floor', a virtual space reproducing the corridor of the Pagliara Museum (part of the Suor Orsola monastic citadel complex), within which the exploration begins.

Currently, the platform hosts the following exhibitions: Da Roma verso Sud. La veduta e l'Antico nelle acqueforti di Piranesi (Views and Antiquity in the Etchings of Piranesi), The Virtual Exhibition of Pietro Scoppetta, The Princess's Drawing Room, MoDa (Many Things to See), Napoleon Virtual Tour.

## 4. Pre-prototyping Aldrovandi

A common need and a starting point of all above mentioned museums and collections, is the digital acquisition, processing, metadata and sharing of the artworks and objects. For this reason we have chosen a common preliminary research project, to better identify a common approach and procedure.

Since all Spoke 4 core case studies are concerned with the digitisation and virtualisation of cultural heritage objects, one of the first goals of Spoke 4 has been to identify a set of guidelines that can support the researchers and other members of the Spoke to set up



appropriate cultural heritage acquisition processes. Thus, before the development of final solutions for the case studies, we have decided to start working on an exemplary research project that could serve as a common experimental ground for a multidisciplinary group and as a baseline to define some approaches and methods that would then be adopted by the partners in the development of the core case studies. These methods included the acquisition, processing, optimisation, metadata inclusion and online publication of 3D assets. We decided to work on a temporary exhibition (which ended on the 28th of May 2023) entitled "The Other Renaissance: Ulisse Aldrovandi and the Wonders of the World". That was the perfect starting point for our work, considering a large set of different small/medium objects to be acquired.

The overall goal was to obtain a digital version of the experience at the exhibition, starting from its digital twin, connected to the digital asset of the different items (3D and multimedia) of the collections, organised and accessible online by users, using various devices (from home computers, smartphones, to tablets and VR headsets). In particular, we have identified four main research questions (RQ1-RQ4) to be addressed:

1. How to preserve and make accessible temporary exhibitions and specifically the potential experience a visitor can have?
2. What is the impact of environmental, temporal and contextual constraints (i.e. objects in glass cases, mandatory short time of acquisition, etc.) in the final digital result and how to keep track of this impact in the final stored or even visualised object?
3. How to handle, acquire and process objects made of critical and peculiar material (such as grass, dimension, fur, and metal)?
4. How to realise the entire data flow, from the management of the acquisition process to digital data and metadata on-line access for experts, from metadata storage to interactive experiences, such as virtual exhibitions/virtual museums or digital libraries?

The exhibition "The Other Renaissance: Ulisse Aldrovandi and the wonders of the world" (<https://site.unibo.it/aldrovandi500/en/mostra-l-altro-rinascimento>) was held in Poggi Palace Museum (Via Zamboni 33, Bologna, Italy) between December 2022 and May 2023. Aldrovandi's theatre of nature in Bologna represented a unicum in 16th-century Europe (Pomian, 2020). The creation of a digital manifestation of the exhibition was therefore also conceived to broaden the audience of people interested in this ancient message of peaceful knowledge, which, by the way, represents one of the cornerstones of the University identity worldwide. The exhibition was conceived to guide visitors to discover what was called the "reawakening of natural sciences", a moment of the Renaissance, in which the naturalist Ulisse Aldrovandi in Bologna and a small group of doctors, pharmacists and naturalists (who first studied animals and plants from life, rather than just in books), took the first steps

towards science as we know it today (Rebellato, 2018). The exhibition was developed in six rooms of the Palace. This collection of 'jewels', most of which have never been exhibited before, included objects and works of art from other Italian museums, but also multimedia material included in the itinerary (Haxhiraj, 2016). This unique exhibition received a high appreciation from the public (more than 30,000 visitors). As it was a temporary exhibition, its conclusion was perceived as a lost occasion for the many potential other citizens and scholars who could have been interested in revisiting it. This open issue, common to the many temporary exhibitions around the world, has led us to use it as an exceptionally appropriate case to focus on this priority and search for potential solutions supported by virtual technologies.



One of the room of the exhibition at Palazzo Poggi. source: <https://site.unibo.it/aldrovandi500/en/mostra-l-altro-rinascimento>.

To maximise the re-adoption of the workflow for the creation of a virtual exhibition in other contexts (internally or externally to Spoke 4), we tried to use open tools and software as much as possible for every single step of the process. However, we also used appropriate proprietary software when we thought it would suit some tasks. In addition, following the prescription of the Spoke 4 Data Management Plan (Gualandi and Peroni, 2023), we decided to use as many as possible standard formats for all the types of research data we generate – 3D models (glTF, GLB, obj, mtl, png, tiff, jpg, e57), images (tiff, png, jpg, raw), video (mp4, mov), and audio (mp3) – as not to be bound to any proprietary software applications. In particular, regarding 3D formats, we pushed the adoption of glTF, an interoperable open standard targeting interactive Web3D applications to guarantee high interoperability with existing 3D platforms/services, re-use and integration of licensing information inside the format. In terms of licenses used for publishing the various research data, we tried to be as open as possible.

Our overall goal was to let visitors and experts access the temporary exhibition after its closing. We therefore have planned to start with the creation of a Digital Twin as a necessary step to develop more complex VR experiences, such as Virtual Museums (Pescarin, 2014). The digital exhibition as it is planned will provide at least an additional level of interaction which was impossible in the physical environment: to go beyond the purely static observation of the objects behind the display cases and take such objects with digital hands, zooming and rotating them as the users prefer. Thus, the digital approach allows users to explore the breadth and depth of Aldrovandi's work.

Temporary exhibitions, such as many museum exhibitions, present several problems from the point of view of digitisation (Gattet et al., 2015; Di Paola et al., 2022; Farella et al., 2022). The three main complexities encountered in the literature were related to time, space, and materials. The first constraint, related to the time factor, was a direct consequence of the temporary nature of an exhibition, just as it may well be related to the short acquisition time a project may have. The second complexity involves space: in approaching acquisition, one has to deal with coordination among the various research groups and the lack of support, the scarcity of electrical outlets, suitable lighting conditions, and the few "manoeuvring spaces" available. A further problem regarding acquisition concerns the materials of which some works are composed: several objects may present non-cooperative or hybrid materials, including specular components that could influence the optical response of the detection instruments, such as black, glossy or transparent surfaces (Bruno et al., 2010; Guidi et al., 2010).

In the creation of the Digital Twin of the exhibition, as a first necessary step, we planned to acquire the entire collection on display, together with the multimedia content available to the visitors and the physical spaces (the rooms). The acquisition of most objects and environments lasted three months (from the end of March 2023 to the end of June 2023).

We spent a total of 91 hours for the entire acquisition process.

The work was carried out by 6 acquisition teams, the staff of 3 museums and one library and specialised external professionals, specifically:

- researchers and students from five Departments of the University of Bologna (Architecture; Civil, Chemical, Environmental, and Materials Engineering; Classical Philology and Italian Studies; Cultural Heritage; History and Culture);
- researchers from the Digital Heritage Innovation Lab of CNR ISPC (Florence and Rome branches);
- managers and staff of the University of Bologna Museum Network;
- managers and staff of the Bologna University Library;
- staff of the Archeological Museum of Bologna;

- staff of the Medieval Civic Museum of Bologna;
- professionals specialised in the removal and reinstalling of display cases.

To reach the project objectives, we have identified and set up a common protocol that would have guided us. Before starting this acquisition, to avoid wasting working effort, we assessed all the pieces included in the exhibition. We organised the acquisition of the remaining pieces focusing first on the objects that were borrowed from other cultural heritage institutions and that had to be returned. For some of these objects, it was compulsory to acquire them together with a representative staff of the source institution, who should assist the process.



*Researchers acquiring different types of objects using a structured light projection scanner (left) and photogrammetric techniques (right) and using supports such as a camping table (left) and a marble table (right)*

Each team was required to collect their workflow procedures and processes and update a shared file. They did this by listing the metadata in a shared spreadsheet on a cloud-based service (Sharepoint). storing the spreadsheet in the cloud allowed multiple contributors to make real-time updates and contributions simultaneously. This resulted in an efficient compilation of the comprehensive metadata table, with input from each group. Additionally, the cloud platform provided features for peer review, enabling members to examine each other's work and an open environment that supported the transparent exchange of information. The metadata table was directly related to the various activities and was organised as a spreadsheet with multiple separated columns according to the different stages to be performed on each object, described in the following subsections.

The initial stage of the process (step 1) aimed to capture and acquire analogue materials to create their digital representation. This stage was followed by several software activities (steps 2-7), i.e. the series of phases that involve using various software tools and applications

to process, transform, and publish the digital versions of the material acquired during the acquisition phase.

- Processing phase (step 2) – software tools are used to process and manipulate the digital files produced during the acquisition phase;
- Modelling phase (step 3) – software tools are used to create a digital model of the object or space;
- Optimization phase (step 4) – software tools are used to optimise the digital files for specific purposes or use cases;
- Export phase (step 5) – software tools are used to export the digital files in a specific format or for a specific purpose;
- Metadata creation phase (step 6) – software tools are used to create structured metadata that describes the content and context of the digital files
- Upload phase (step 7) – software tools are used to transfer digital 3D models from a local device or storage location to a Web-based framework (e.g. ATON).

The objects in the exhibition "The Other Renaissance" were in total 301.

Objects displayed very diverse characteristics, both in their geometric shapes and surface properties, adding a further constraint to those already mentioned above (i.e. time and space). Digitisation involved many materials, including paper-based objects such as manuscripts, printed volumes, and ancient maps. Moreover, there were numerous woodcuts, technical/scientific instruments, statues, specimens, and archaeological finds.

Handling such a vast and diverse collection required the application of established techniques. As a result, the acquisition process relied on well-tested remote-sensing technologies commonly used in cultural heritage preservation, such as 3D structured light projection scanning and digital photogrammetry (Bitelli et al., 2007; Apollonio et al., 2021).

In total we have acquired 104 specimens, 27 printed volumes, 17 manuscripts, 5 nautical charts and maps, 1 diorama, 7 herbariums, 21 models, 7 woodcuts, 3 paintings, 6 painted ceilings, 11 casts, 2 medals, 4 scientific instruments and more than 30 other objects, including archaeological remains; among multimedia assets, we have acquired 9 videos, 2 prints and 27 panels with graphics.

Moreover we have created a mockup of the original exhibition to be used as a common and shared reference during the creation of the Digital Twin. Due to the mentioned time constraints, we have chosen as a viable solution 360 panoramas Virtual Tour (VT) technology.

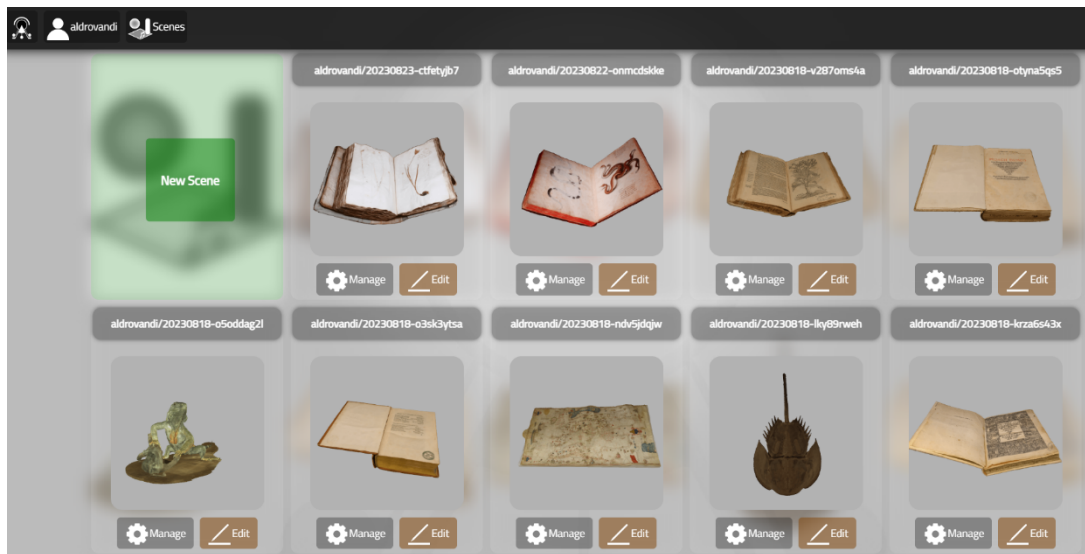




*One of the equirectangular panoramas captured to create the VR tour*

Since we did not need to obtain super-high-resolution images, we adopted a fast technique, employing an Insta360 ONE X2, a dual-lens 360 action camera conceived for capturing panoramic videos and images up to 5.7 K.

After the conclusion of the 3D survey and processing, we worked on the optimisation of the geometry and textures of each model. The starting input was the highest resolution model, obtained after photogrammetry or scanner post-processing (level 0). We have first processed all level 0 models through Instant Meshes, a software that employs a cohesive local smoothing algorithm to re-mesh the surface, enhancing both the edge orientations and vertex positions in the resulting mesh (Jakob et al., 2015). This first processing returned a regular topology. The missing parts have been manually modelled, using references, integrating them and optimising through editing and sculpting tools in Blender. Once the model was fixed in terms of topological issues, a further re-meshing in Instant Mesh was performed to give a regular topology to the reconstructed parts of the mesh and to obtain the final level 1 model. The final step required to optimise these models (level 2). To perform the texture building and mapping, each model parametrised in Blender has been exported in obj format. Finally, each model has been exported in glTF format (Robinet et al., 2014), suitable for the navigation and sharing in Web3D applications of each 3D item involved in the exhibition. The export was performed following straightforward guidelines specifically designed for the Web3D platform adopted in this project (<https://osiris.itabc.cnr.it/aton/index.php/tutorials/creating-3d-content-for-aton/exporting-3d-models-from-blender/>). Since our goal was to obtain realistic and metadata-enriched models accessible online in 3D and from different devices, we have decided to publish each post-processed model using the above mentioned ATON, the open-source framework developed by the CNR-ISPC (Fanini et al. 2021).



The Aton digital library with the single 3d digital objects

As a final step, we have worked on Metadata collection, curation, and modelling.

From this experience we gained a number of lessons learnt and an optimal workflow and best practice guide to be applied to the other case studies of the Spoke.

A complete publication is currently under review, submitted to Elsevier Journal of Digital Applications in Archaeology and Cultural Heritage (Barzaghi et al 2023, Balzani et al 2023).

## References

Balzani, R., Barzaghi, S., Bitelli, G., Bonifazi, F., Bordignon, A., Cipriani, L., Colitti, S., Collina, F., Daquino, M., Fabbri, F., Fanini, B., Fantini, F., Ferdani, D., Fiorini, G., Formia, E., Forte, A., Giacomini, F., Girelli, V. A., Gualandi, B., ... Vittuari, L. (2023). *Saving temporary exhibitions in virtual environments: The Digital Renaissance of Ulisse Aldrovandi*. <https://doi.org/10.48550/arXiv.2308.15920>

Barzaghi, S., Collina, F., Fabbri, F., Giacomini, F., Bordignon, A., Balzani, R., Bitelli, G., Bonifazi, F., Cipriani, L., Colitti, S., Daquino, M., Fanini, B., Fantini, F., Ferdani, D., Fiorini, G., Formia, E., Forte, A., Girelli, V. A., Gualandi, B., ... Vittuari, L. (2023). Digitisation of Temporary Exhibitions: The Aldrovandi Case. In A. Bucciero, B. Fanini, H. Graf, S. Pescarin, & S. Rizvic (Eds.), *Proceedings of the 21st Eurographics Workshop on Graphics and Cultural Heritage (GCH 2023)*. The Eurographics Association. <https://doi.org/10.2312/gch.20231176>

Banyon D. (2014). *Designing Interactive Systems. A Comprehensive Guide to HCI, UX and Interaction Design*. Pearson ed., pp. 138-165

Barrett, W.A., Mortensen, E.N., "Interactive live-wire boundary extraction", Medical image analysis, 1(4) (1997), 331-341.

BECK J., RAINOLDI M., EGGER R.: Virtual reality in tourism: a state-of-the-art review. Tourism Review, Vol. 74 No. 3, 2019, 586-612

Bolter, J. D. e Grusin, R. A. (1996). Remediation. Configurations, 4(3), 311-358.

Bonfigli, M. E., Forte, M., Guidazzoli, A., Pescarin, S., & Zane, M. (2004). The Aksum project: a VR GIS for a 3D inclusive interaction with an archaeological landscape.

Brown, L.G., "A survey of image registration techniques", ACM computing surveys (CSUR) 24.4 (1992), 325-376.

Bruni, L. E., Daga, E., Damiano, R., Diaz, L., Kuflik, T., Lieto, A., et al. (2020). Towards Advanced interfaces for citizen curation. In AVI2CH@ AVI.

Bruner, J. (1991). The narrative construction of reality. Critical inquiry, 18(1), 1-21.

Campbell, J. (2008). The hero with a thousand faces (Vol. 17). New World Library.

Carfagni, M., Furferi, R., Governi, L., Volpe, Y., Tennirelli, G., "Tactile representation of paintings: An early assessment of possible computer based strategies", Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 7616 LNCS (2012), 261-270.

Carroll, N. (2007). Narrative closure. Philosophical studies, 135, 1-15.

CHO Y., WANG Y., FESENMAIER D.: Searching for experiences: The web-based virtual tour in tourism marketing. Journal of Travel & Tourism Marketing 12.4 (2002): 1-17

Covid 2021. Follow-up survey on the impact of the COVID-19 pandemic on museums in Europe. Nemo Final Report, Jan 2021

B. Fanini, D. Ferdani, E. Demetrescu, S. Berto, E. d'Annibale (2021). *ATON: An Open-Source Framework for Creating Immersive, Collaborative and Liquid Web-Apps for Cultural Heritage*. Applied Sciences, 11(22), 11062.

Crowdsourcing Cultural Heritage: From 3D Modeling to the Engagement of Young Generations.

Currie, G. (2009). Narrative and the Psychology of Character. *The journal of aesthetics and art criticism*, 67(1), 61-71.

Daga, E., Asprino, L., Damiano, R., Daquino, M., Agudo, B. D., Gangemi, A., et al. (2022). Integrating citizen experiences in cultural heritage archives: requirements, state of the art, and challenges. *ACM Journal on Computing and Cultural Heritage (JOCCH)*, 15(1), 1–35.

Damiano, R., Lombardo, V., e Pizzo, A. (2019). The ontology of drama. *Applied ontology*, 14(1), 79-118.

Damiano, R., Lombardo, V., Lieto, A., e Borra, D. (2016). Exploring cultural heritage repositories with creative intelligence. The Labyrinth 3D system. *Entertainment Computing*, 16, 41-52.

Damiano, R., e Lieto, A. (2013). Ontological representations of narratives: a case study on stories and actions. In *2013 Workshop on Computational Models of Narrative* (pp. 76-93). Schloss Dagstuhl Leibniz-Zentrum für Informatik.

Di Angelo, L., Di Stefano, P., "Bilateral symmetry estimation of human face", *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 2012, 1-9.

Durou, J.-D., Falcone, M., Sagona, M., "Numerical methods for shape-from-shading: A new survey with benchmarks", *Computer Vision and Image Understanding*, 109 (2008), 22-43.

Fanini, B., d'Annibale, E., Demetrescu, E., Ferdani, D., & Pagano, A. (2015, September). Engaging and shared gesture-based interaction for museums the case study of K2R international expo in Rome. In *2015 Digital Heritage* (Vol. 1, pp. 263-270). IEEE.

Furferi, R., Governi, L., Vanni, N., Volpe, Y., "Tactile 3D bas-relief from single-point perspective paintings: a computer based method", *Journal of Information and Computational Science*, 11 (16) (2014), 1 -14, ISSN:1548-7741.

Frankot, Robert T., and Rama Chellappa. "Estimation of surface topography from SAR imagery using shape from shading techniques." *Artificial Intelligence* 43.3 (1990): 271-310.

Forte, M., Pescarin, S., Pietroni, E., & Rufa, C. (2006). Multiuser interaction in an archaeological landscape: the Flaminia project. *BAR International Series*, 1568, 189.

Gallerie degli Uffizi, "Uffizi da mangiare" LINK: <https://www.uffizi.it/video-storie/uffizi-da-mangiare>

Genovese, G., Russo, E., (2021) Rinascimento digitale. Percorsi progetti esperimenti, Roma, Treccani

Gershon, N., e Page, W. (2001). What storytelling can do for information visualization. Communications of the ACM, 44(8), 31-37.

Gervás, P. (2013). Propp's Morphology of the Folk Tale as a Grammar for Generation. In 2013 Workshop on Computational Models of Narrative. Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik.

Governi, L., Carfagni, M., Furferi, R., Puggelli, L., Volpe, Y., "Digital Bas-Relief Design: A Novel Shape from Shading-Based Method", Computer-Aided Design and Applications, 11 (2) (2014), 153-164.

Hightet, G. (1949). The classical tradition: Greek and Roman influences on Western literature. Oxford University Press, USA

Hoiem, D., Efros, A.A., Martial, H., "Automatic photo pop-up", ACM Transactions on Graphics (TOG). Vol. 24. No. 3. ACM (2005).

Horry, Y., Anjyo, K., Arai, K., "Tour into the picture: using a spidery mesh interface to make animation from a single image", Proceedings of the 24th annual conference on Computer graphics and interactive techniques, ACM Press/Addison-Wesley (1997).

Huang, Z. K., Zhang, X. W., Zhang, W. Z., Hou, L. Y., "A New Embossing Method for Gray Images Using Kalman Filter", Applied Mechanics and Materials 39 (2011), 488-491

Katz, J. E., & Halpern, D. (2015). Can virtual museums motivate students? Toward a constructivist learning approach. Journal of Science Education and Technology, 24, 776-788.

Kerber, J., "Digital art of bas-relief sculpting", Master's thesis, Univ. of Saarland, Saarbrücken, Germany (2007).

Kingsland, K. (2020). Comparative analysis of digital photogrammetry software for cultural heritage. Digital Applications in Archaeology and Cultural Heritage, 18, e00157.

Klatzky, R.L., Lederman, S.J., & Reed, C.L., "There's more to touch than meets the eye: the salience of object attributes for haptics with and without vision", Journal of Experimental Psychology: General 116 (1987), 356-369.



Kosara, R., e Mackinlay, J. (2013). Storytelling: The next step for visualization. *Computer*, 46(5), 44-50.

Li, Z., Wang, S., Yu, J., Ma, K.-L., "Restoration of brick and stone relief from single rubbing images", *Visualization and Computer Graphics*, IEEE Transactions on, 18 (2012), 177-187.

Lieto, A., Pozzato, G. L., Striani, M., Zoia, S., & Damiano, R. (2022). Degari 2.0: A diversity-seeking, explainable, and affective art recommender for social inclusion. *Cognitive Systems Research*

Lieto, A., Pozzato, G. L., Zoia, S., Patti, V., & Damiano, R. (2021). A commonsense reasoning framework for explanatory emotion attribution, generation and re-classification. *Knowledge- Based Systems*, 107166

Antonio Lieto, Manuel Striani, Cristina Gena, Enrico Dolza, Anna Maria Marras, Gian Luca Pozzato & Rossana Damiano (2023) A sensemaking system for grouping and suggesting stories from multiple affective viewpoints in museums, *Human-Computer Interaction*, DOI: 10.1080/07370024.2023.2242355

Ling, Z., S. Ruoming, and Z. Keqin. 2007. "Rule-based 3D modeling for chinese traditional architecture." In *3D-ARCH 2007*, edited by Fabio Remondino and Sabry El-Hakim. Zürich.

Lombardo, V., Damiano, R., e Pizzo, A. (2019). Toolkit for the Creation of a Drama Dataset. In *International Conference on Interactive Digital Storytelling* (pp. 282-289). Springer, Cham.

Lombardo, V., e Damiano, R. (2012). Semantic annotation of narrative media objects. *Multimedia Tools and Applications*, 59(2), 407-439.

MARASCO A., BUONINCONTRI P., VAN NIEKERK M., ORLOWSKI M., OKUMUS F.: Exploring the role of next-generation virtual technologies in destination marketing. *Journal of Destination Marketing & Management*, 2018

Meghini, C., Bartalesi, V., & Metilli, D. (2021). Representing narratives in digital libraries: The narrative ontology. *Semantic Web*, 12(2), 241-264.

Metodo Amuse, Le nuove frontiere dell'esperienza museale, 3 maggio 2021 – <https://www.metodoamuse.it/le-nuove-frontiere-dellesperienza-museale/>

Milosz, M., Skulimowski, S., Kęsik, J., & Montusiewicz, J. (2020). Virtual and interactive museum of archaeological artefacts from Afrasiyab—An ancient city on the silk road. *Digital Applications in Archaeology and Cultural Heritage*, 18, e00155.

Musei Vaticani, Tour virtuali –

<https://www.museivaticani.va/content/museivaticani/it/collezioni/musei/tour-virtuali-elenco.html>

Münster, Sander, Kristina Friedrichs, and Wolfgang Hegel. "3D reconstruction techniques as a cultural shift in art history?." *International Journal for Digital Art History* 3 (2019): 39-59.

Nadernejad, E., Sharifzadeh, S., Hassanpour, H., "Edge detection techniques: evaluations and comparisons", *Applied Mathematical Sciences*, 2 (31) (2008), 1507-1520.

Pescarin S., Cerato I., D'Annibale E., Fanini B., Ferdani D., Manganelli Del Fà R., Marasco A., Massidda M., Palombini A., Ronchi D. (2023). Hybrid XR collaborative and guided experiences in Cultural Heritage: Brancacci POV prototype. In *EUROGRAPHICS Workshop on Graphics and Cultural Heritage* (2023: A. Bucciero, B. Fanini, H. Graf, S. Pescarin and S. Rizvic Editors)

Pietroni, E., Forte, M., Pescarin, S., & Rufa, C. (2005, November). The virtual reconstruction of archaeological landscape: from the fieldwork to the communication through real time applications. The digital narrative museum of the Appia Antica Park. In *Virtual Retrospect 2005* (Vol. 2, pp. 134-139). Ausonius.

Pietroni, Eva, and Andrea Adami. "Interacting with virtual reconstructions in museums: The Etruscanning Project." *Journal on Computing and Cultural Heritage (JOCCH)* 7.2 (2014): 1-29.

Pietroni, E., Palombini, A., Sanna, V., & Arnoldus-Huyzendveld, A. (2013, October). Tiber Valley Virtual Museum: 3D landscape reconstruction in the orientalising period, North of Rome: A methodological approach proposal. In *2013 Digital Heritage International Congress (DigitalHeritage)* (Vol. 2, pp. 223-230). IEEE.

Pietroni, Eva, Massimiliano Forlani, and Claudio Rufa. "Livia's Villa Reloaded: An example of re-use and update of a pre-existing Virtual Museum, following a novel approach in storytelling inside virtual reality environments." *2015 Digital Heritage*. Vol. 2. IEEE, 2015

Polti, G. (1924). *Les trente-six situations dramatiques*. Mercure de France, Paris.

Rasiya, G., Shukla, A., & Saran, K. (2021). Additive manufacturing-a review. *Materials Today: Proceedings*, 47, 6896-6901.

Reichinger, A., Maierhofer, S., Purgathofer, W., "High-quality tactile paintings", Journal on Computing and Cultural Heritage, 4 (2) (2011) Art. no.5.

Reichinger, A., Neumüller, M., Rist, F., Maierhofer, S., Purgathofer, W., "Computer-Aided Design of Tactile Models - Taxonomy and Case Studies", in Miesenberger, K., Karshmer, A., Penaz, P., Zagler, W., eds.: Computers Helping People with Special Needs. 7383 Volume of Lecture Notes in Computer Science. Springer Berlin / Heidelberg (2012), 497-504.

Remondino, Fabio. "Heritage recording and 3D modeling with photogrammetry and 3D scanning." Remote sensing 3.6 (2011): 1104-1138.

RESTA G., DICUONZO F., KARACAN E., PASTORE D.: 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), 2021, 151-166

Sartini, B., Baroncini, S., van Erp, M., Tomasi, F., & Gangemi, A. (2023). ICON: an Ontology for Comprehensive Artistic Interpretations. ACM Journal on Computing and Cultural Heritage.

Salvatore Scarfone, Ricostruzione virtuale dell'Acropoli di Atene – <https://salvatorescarfone.it/portfolio/acropoli-di-atene-ricostruzione/>

Schindler, I., Hosoya, G., Menninghaus, W., Beermann, U., Wagner, V., Eid, M., et al. (2017). Measuring aesthetic emotions: A review of the literature and a new assessment tool. PLoS One, 12(6), Article e0178899.

Shibolet, Y., & Lombardo, V. (2022, December). Resources for comparative analysis of IDN authoring tools. In International Conference on Interactive Digital Storytelling (pp. 513-528). Cham: Springer International Publishing.

Spelke, E. S., "Haptic perception of objects in infancy", Cognitive Psychology 20 (1) (1988), 1-23. Sourin, Alexei. "Functionally based virtual computer art." Proceedings of the 2001 symposium on Interactive 3D graphics. ACM, 2001.

Thompson, L., Chronicle, E., "Beyond visual conventions: Rethinking the design of tactile diagrams", British Journal of Visual Impairment, 24 (2) (2006), 76-82.

Thompson, S. (1955). Myths and folktales. Journal of American Folklore, pp. 482-488.

Tost, L. P., & Economou, M. (2009). Worth a thousand words? The usefulness of immersive virtual reality for learning in cultural heritage settings. *International Journal of Architectural Computing*, 7(1), 157-176.

Van Dongen, N. N., Van Strien, J. W., & Dijkstra, K. (2016). Implicit emotion regulation in the context of viewing artworks: ERP evidence in response to pleasant and Unpleasant pictures. *Brain and Cognition*, 107, 48–54.

Volpe, Y., Furferi, R., Governi, L., Tennirelli, G., "Computer-based methodologies for semi-automatic 3D model generation from paintings", *Int. J. Computer Aided Engineering and Technology*, 6 (1) (2014), 88-112.

Wang, M., Chang, J., Zhang, J. J., "A review of digital relief generation techniques", *Computer Engineering and Technology (ICCET)*, 2010 2nd International Conference on, IEEE (2010), 198–202.

Weyrich, T., et al., "Digital bas-relief from 3D scenes", *ACM Transactions on Graphics (TOG)* 26 (3) ACM (2007).

Wu, J., Martin, R.R., Rosin, P.L., Sun, X.-F., Lai, Y.-K., Liu, Y.-H., Wallraven, C., "Use of non-photorealistic rendering and photometric stereo in making bas-reliefs from photographs", *Graphical Models*, 76 (4) (2014), 202-213, ISSN 1524-0703, <http://dx.doi.org/10.1016/j.gmod.2014.02.002>.

Wu, J., Martin, R., Rosin, P., Sun, X.-F., Langbein, F., Lai, Y.-K., Marshall, A., Liu, Y.-H., "Making bas-reliefs from photographs of human faces", *Computer-Aided Design*, 45 (3) (2013), 671–682 .

Zarri, G.P. 2014, "Conceptual and content-based annotation of (multimedia) documents," *Multimedia tools and applications*, vol. 72, no. 3, pp. 2359–2391.

Zidianakis, E., Partarakis, N., Ntoa, S., Dimopoulos, A., Kopidaki, S., Ntagianta, A., ... & Stephanidis, C. (2021). The invisible museum: A user-centric platform for creating virtual 3D exhibitions with VR support. *Electronics*, 10(3), 363.

Zuckerberg M., Spot Meta, 5 novembre 2021 –  
<https://www.facebook.com/zuck/videos/1299160977186862/>