Methodological Approach for 1D Simulation of Port Water Injection for Knock Mitigation in a Turbocharged DISI Engine

Reality-Virtuality Continuum Between Heuristic Research and Museum Presentation. Experiences in Reconstructive Modelling and AR Communication

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Abstract.
This research involved a multidisciplinary group of scholars with expertise in Indian art and archaeology, digital representation, and information processing systems, with the support of VR@POLITO and MOD Lab Arch of the Politecnico di Torino.
The paper describes a project aimed at the analysis, interpretive reconstruction, and communication, using physical and digital media, of the features of a Buddha statue kept at the Asian Art Museum in Turin (MAO).
The specific interest in the Buddha Gupta statue is related to the philological reconstruction of the gaps, which has engaged the research group in defining possible alternative references and hypotheses, comparing mounting solutions for one of the forearms, and choosing the most suitable modes of communication.

Keywords: Reconstructive modelling, Augmented reality, Digital fabrication, Museum heritage, Archaeological heritage, Buddha Gupta.

1 Introduction

This research was conducted as part of the agreement between the Politecnico di Torino and the Fondazione Torino Musei to enhance museum heritage through digital methodologies and technologies.

The work involved a multidisciplinary group of scholars with expertise in Indian art and archaeology, digital representation, and information processing systems, with the support of VR@POLITO and MOD Lab Arch of the Politecnico di Torino.

The present paper describes a part of the overall project; this last aimed at the analysis, interpretive reconstruction, contextualisation and communication of the evolution of statuary depicting Buddha in the Indo-Pakistani area. This process has been read through artworks housed at the Asian Art Museum in Turin (MAO), affiliated with the Fondazione Torino Musei. The research focuses on a standing Buddha statue from the mid-Gupta period in the Mathura area (India). The piece, carved in spotted red sandstone, arrived incomplete with the lower part of both legs. Consequently, the hem at the bottom of the robe, the left hand and right forearm, a substantial portion of the halo, and some fragments of the face and hair (Fig. 1). The specific interest in the Buddha Gupta statue, within the broader context of the research described above, is related to the philological reconstruction of the gaps, which has engaged the research group in numerous meetings to define possible alternative references and hypotheses, to compare mounting solutions for one of the forearms, and to choose the most suitable modes of communication.

Fig. 1. On the right, the Buddha Gupta at the Asian Art Museum in Turin (MAO). Photo: F. Ronco.

2 XR and Museum Heritage

By the principles of new museology [1], museums are not to be considered as just static places where artefacts are preserved but as dynamic entities that are expected to evolve into engaging experiences. They should encourage visitors' involvement, participation and learning, transforming themselves from simple exhibition spaces into immersive educational contexts [1], [2]. In this effort to focus on visitor-centred engagement, museums are increasingly adopting new digital tools, offering their audiences an immersive, interactive, and multi-sensory experience that is not possible in traditional exhibitions. Within this context, a key concept playing an increasingly relevant role is that eXtended Reality (XR) [3] represent an umbrella term encompassing three different technologies.

Augmented Reality (AR) provides the user with additional synthetic content augmenting the physical environment [4]. Virtual Reality (VR), in turn, immerses the user in a fully synthetic environment featuring realistic or fictional content [4]. Finally, with Mixed Reality (MR), the physical and virtual worlds are blended [5], coexisting and interacting in real time. In the field of cultural heritage, AR and MR are typically used in location-based applications, e.g., to enhance physical exhibitions by overlaying additional content, whereas VR technology is often exploited to let users overcome the limitations of time and space, providing access to lost or damaged historical places or artefacts [6].

For instance, in [7], an XR platform is presented to enable the exploration and interaction with a three-dimensional reconstruction of the Pleito Cave, an archaeological site in California, USA. This is just an example of how, with XR, it is possible to engage the users in carefully replicated environments through 3D reconstruction techniques (e.g., photogrammetry, laser scanning), opening up the possibility of remote visits.

The use of XR can be applied not only to large environments but also to small, detailed artefacts. For example, the work presented in [8] proposes an XR experience built around a ritual of ancient Egypt, which aims to improve users understanding and involvement through direct interaction with the virtual reconstruction of original objects. By wearing a headset, users can explore digital replicas of specific objects, like a wooden sarcophagus and a heart scarab, naturally interacting with them through hand tracking. While manipulating the objects, they can obtain hieroglyph translations via a dedicated user interface.

Another example is the work presented in [9], where the authors present an interactive XR application that depicts a reconstruction of the Temple of Ptah at Karnak, proposing two hypotheses regarding the initial positioning of the statues of the goddess Sekhmet. The application starts with an initial passive scene where a narrating voice introduces the experience, followed by a phase in which the user can, using a common locomotion technique (teleporting) [10], explore the reconstructed environment. During the exploration, the user can interact with certain virtual elements that trigger audio explanations related to the area where they are located, possibly even altering parts of the virtual environment based on the presented concepts.

In the context of XR, museum professionals have discovered the potential of creating completely virtual exhibitions, freeing them from the possible limitations of the physical museum [11]. Although this approach represents a fascinating way to attract people to visit exhibitions, it is seen as a complementary strategy rather than a replacement for physical experiences [1]. The literature successfully documents the integration into existing visits of XR experiences that foster experiential learning, a crucial aspect of museum engagement [10].

This convergence between technology and heritage conservation illustrates the transformative potential of XR in the museum landscape. In addition to improving the accessibility and educational value of museums, XR can contribute to the preservation and understanding of cultural heritage. In the evolving digital age, the use of this technology in museums is seen as a tool that can enhance the traditional museum experience and extend the possibilities of what can be achieved in the relevant contexts of education, conservation, and engagement.

3 The Buddha Gupta at MAO and the References for Reconstructive Hypotheses

Digital methodologies and technologies are increasingly used in archaeological and museographic fields, not only for the geometric, metric, and chromatic acquisition of artefact features and their representation through 3D digital models but also to imagine new keys to interpret missing parts and related reconstructive hypotheses. Different interpretations enable further research and generate debate among scholars. They also increase the level of knowledge of visitors with innovative ways of communication.

The reconstruction of the gaps refers to iconographic documentation of similar and coeval works kept in international museums [12], retrieved by Claudia Ramasso, curator at MAO, and the author of this paragraph, who heads the Italian Archeological Mission in Pakistan (ISMEO and Ca' Foscari University of Venice). According to the principles of digital archaeology, the missing parts were modelled without applying textures to ensure the distinguishability of the original part and the reconstruction.

The statue object of this research is a fine sculpture of Buddha from the height of the Gupta period, in typical Mathurā spotted red sandstone, received incomplete to the present day. The folds of the robe, delicately traced according to one that in Mathurā far outshines the thick draperies of Gandhara art (developed from the 1st to 3rd-4th centuries CE), adhere tightly to the body, leaving the sensuous forms characteristic of Indian Buddhist sculpture of this phase and those immediately following. The idealised image of the Buddha presents the head slightly tilted forward with a downward gaze. The mouth, with full lips characteristic of this style, hints at a restrained smile. The hair is neatly arranged in rows of tiny curls. The halo has a wealth of vegetal motifs succeeding each other in concentric circles around the central lotus corolla. The new refined style of this Buddha is pervaded by an idealised naturalism that imposes itself due to the spirituality of the image.

An artwork comparable to the Buddha Gupta exhibited at MAO is preserved in the Rashtrapati Bhavan, Presidential Palace, New Delhi. This and other correlated statues

are the masterpieces of a later and accomplished development of the Mathurā school of sculpture. They can all be labelled under the over-generic term of Early Gupta art and dated around between the 2nd and the 4th century CE.
Immaculate red sandstone characterises many of these late-period statues. The statues always depict a standing Buddha in the act of reassurance, while his left-hand holds the hem of the monastic robe and may or may not have a large round halo, sometimes assembled. Formally, the origin of these statues, carved in the round, originate in early Mathurān art; by way of example, one may recall the famous Bala Bodhisattva of Sarnath, dated 131 CE (year 3 of the Kanishka era), published in [12].
An outstanding piece of art is also the sculpture from Monoharpura, Mathura, Uttar Pradesh, now in the Government Museum of Mathura [13]. Other important pieces are those preserved in the Freer Gallery in the Smithsonian Institution, Washington, D.C. [14], and the Metropolitan Museum of Art [15].

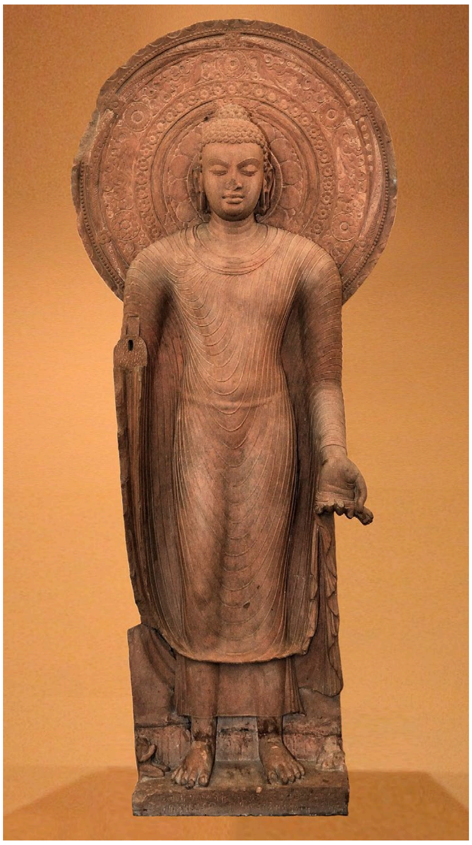

Fig. 2. Left: Jamalpur standing Buddha. https://en.wikipedia.org/wiki/File:Standing_Buddha_Installed_by_Buddist_Monk_Yasadinna_-_Circa_5th_Century_CE_-_Jamalpur_Mound_-_ACCN_00-A-5_-_Government_Museum_Mathura_Golden_background.jpg. Right: Reconstructive modelling of Buddha Gupta at MAO. 3D modelling: L. Castagna.

The identification of a key to the proper forearm connection, rather than a fracture in the stone as the cause of the loss of that part of the statue, was possible through comparison with other works such as the Jamalpur standing Buddha (Fig. 2) in the Government Museum, Mathura [16].
Another reference is the standing Buddha, from Govindnagar, Uttar Pradesh, kept in the Government Museum of Mathura [12], particularly for one of the reconstruction hypotheses for the position of the right forearm lying forward at torso level. The second hypothesis may refer to the position of the same forearm bent parallel to the arm, as in the Bodhisattva (?) di Ganeshra at the Lucknow State Museum [12] and the standing Buddha of the "Kapardin" type, Early Kushan period in the Government Museum, Mathura.

4 Pipeline and Methodology

The pipeline has been developed through archaeological and historical study, the digital survey using Structure from Motion (SfM) technology, and the 3D modelling of the artwork. Then, the philological-reconstructive modelling of the missing parts, with two different hypotheses about one of the forearms, has been realised. Finally, the communication through small-scale physical replica, realised with digital fabrication and aimed at inclusive communication, and through Augmented Reality (AR), containing a static reconstruction, an animation, and other content, has been set up (Fig. 3).
The choice of AR technology was guided by the desire to make visitors appreciate new aspects of the work, increasing the degree of knowledge during the on-site visit, and enhancing the overall enjoyment of the museum.

Compared to previous works developed by the research team [17], the present experience is characterised by the circularity of the continuum between real and virtual, beginning and ending with two physical entities: the artwork and its replica.

Reconstructive digital modelling in compliance with The Charter of London (2009) [18] and The Principles of Seville (2012) [19], is central to the process because of its peculiar heuristic value [20], facilitating discussion among scholars at the stage of evaluating reconstructive hypotheses and communication to the public, through reconstructive modelling and animation in AR, which allows understanding of the hypothesised methods of fabrication and assembly [21].

While the halo was easily reconstructed due to the radial modularity of the decorative motif, the analogy with other coeval works belonging to the same area, seen above, suggested the morphology of the lower legs, including the feet and the terminal portion of the drapery. Defining the position of the two hands and the right arm engaged the multidisciplinary team in an extensive examination of coeval examples. The most plausible hypothesis for the left hand was that it held a flap of the robe, while the right hand expressed the gesture of abhayamudrā, the gesture of reassurance. Even more exciting and complex was the reasoning developed about the right forearm.

Fig. 3. Research pipeline. A: photogrammetric survey; B: modelling and texturing; C: reconstructive modelling; D: references for reconstructive modelling; E: content for AR; F: AR experimentation in museum; G: physical modelling. Editing: R. Spallone.

As seen above, what might appear to be a fracture in the stone reasonably could be a key suitable for the interlocking of the forearm, made separately. The position assumed by the forearm could have been stretched forward at the torso level (Fig. 4) or bent parallel to the arm (Fig 5). In the first case, a stone connection in continuity with the upper part of the forearm would have ensured its stability. In both cases, the assembly could have been done through rotation, as demonstrated in the animation accompanying the digital reconstruction. Moreover, making the forearm apart from the statue would have facilitated the carving of the careful drapery covering the upper arm, leaving more space for the use of the sculpture tools.

Fig. 4. Left: standing Buddha from Govindnagar. https://en.m.wikipedia.org/wiki/File: Standing_Buddha_Set-up_by_Buddist_Monk_Yasadinna_-_434_CE_-_Govind_Nagar_-_ACCN_76-25_-_Government_Museum_-_Mathura_2013-02-23_5548.JPG. Right: Detail of digital reconstruction of Buddha Gupta at MAO. 3D modelling: L. Castagna.

The digital model integrating the reproduction of the actual statue with the reconstruction of the missing parts was made with Blender and had to face the goal of AR fruition by the public. For numerous reasons (including avoiding shared device sanitisation processes and inclusive digital education), such fruition mode was designed through personal devices like smartphones. This choice implies the need to build lightweight digital models with even those of the latest generation devices for the broadest possible fruition. The models obtained from photogrammetric acquisition and the reconstructions made through the sculpting technique have a high level of detail characterised by many polygons, making them unsuitable for an AR experience. To lighten the files and allow them to be exported and used later, it was necessary to perform a process called retopology.

This technique aims to reduce the faces of a mesh with many polygons.

Fig. 5. Left: Buddha of the "Kapardin" type. https://en.wikipedia.org/wiki/Art_of_Mathura#/media/File:Standing_Buddha_in_Abhaya_Mudra_and_Head_Enriched_by_Halo_with_Scalloped_Border_-_Govind_Nagar_-_Early_Kushan_Period_-_ACCN_71-105_-_Government_Museum_-_Mathura_2013-02-24_5967.JPG. Right: Detail of digital reconstruction of Buddha Gupta at MAO. 3D modelling: L. Castagna.

In the present prototypical phase of AR, the contents designed to be communicated to the public intend to share the research results, including art-historical descriptions, reconstructive models and animations, and links and comparisons with international museum seats.

The physical model, created at the laboratory directed by Prof. Pedro Cabezos Bernal in the Universitat Politècnica de València (UPV), complements how the work can be communicated through the provision of a tactile experience that is interesting in didactic and inclusionary terms and foreshadows possible further developments for the production of a demountable replica.

5 From SfM to Digital Fabrication

As said, this work is part of a larger project involving several statues from MAO's permanent collection. The selection of artworks is linked to evaluations based on art-historical relevance, carried out by Ramasso, and the artefacts' suitability for the photogrammetric survey.

For the Gupta Buddha, as well as for other artworks, summary sheets were made containing a brief description of it and an evaluation table, where each parameter (manoeuvrability, inspectability, lightenability, roughness, perceptibility of details, opacity, and chromatic richness) was assigned a score from 1 to 5.

The digitisation process of the selected artworks consists of two main steps: the photogrammetric survey and the 3D modelling.

MOD Lab Arch provided the Canon digital camera EOS 6D, equipped with a full-frame sensor, with Canon lens EF 50mm fixed focal length, a height-adjustable tripod, and a remote control to activate the shutter remotely. For the lighting system, on the other hand, the available instrumentation consisted of four tripod lamp holders, two soft boxes (which diffuse the punctual light from the bulb through a front white filter), and two umbrellas (silver black reflecting the light). In order not to vary the position of the lighting points and thus not to distort the processing results using software, during the survey phase, the lights were placed following a half circle around the statue because of its location on the wall, two soft-boxes were placed in front to give the greatest amount of illumination and the two umbrellas on the sides to eliminate additional shadows created (Fig. 6).

The sequence of images is then loaded within Agisoft Metashape software, where the workflow that brings to the textured mesh model is followed (Fig. 7).

The model was then exported in .obj format and imported to Blender to perform a mesh cleaning operation to remove vertices and faces that do not directly belong to the statue.

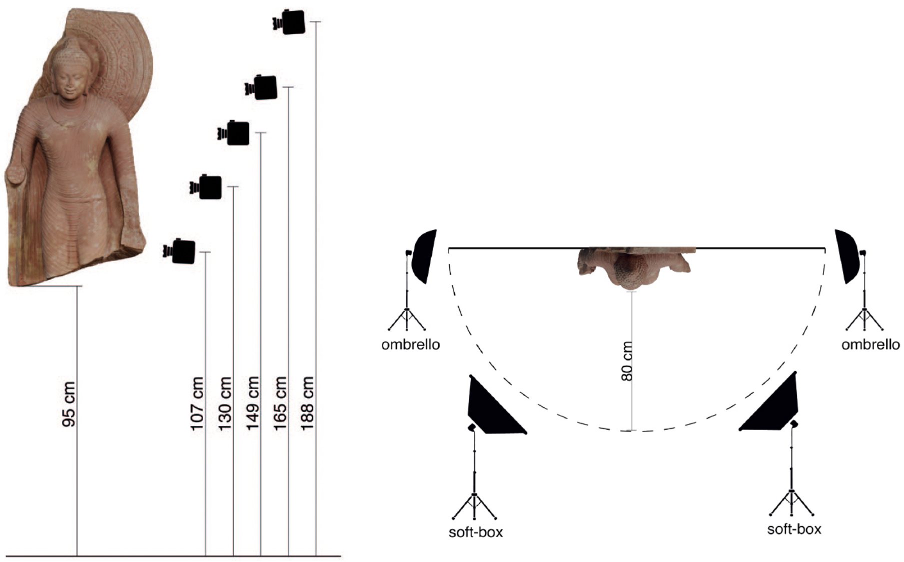

Fig. 6. Scheme of the photogrammetric shooting. Editing: F. Ronco.

Fig. 7. Processing of the point cloud. Editing: F. Ronco.

This operation is helpful in precisely defining the geometry of the statue, lightening the size of the file, and making it more manageable.

To further decrease the weight, the Decimate modifier is used. These two simple steps allowed us to reduce by about ten times the number of vertices.

The final stage involved the prototyping of the sculpture using FDM techniques. In Blender, a surface was generated to close the statue on the back, and the joint male-female between the base and the existing part of the sculpture has been modelled to ensure a suitable and resistant interlock.

The existing portion of the Buddha has a height of 90 cm, and the scale was the first issue addressed for the 3D printing operation.

A scale of 1:5 was chosen for ease of handling, understandable from a possible tactile exploration, taking into consideration, among others, the manual of relief drawing [22] that contains some indications referring to two-dimensional representations but that can be applied to three-dimensional objects. One of the principles is to allow the reader/user an easy "view" of the figure as a whole based on the simultaneous use of two hands.

Parts made the replica, each equipped with male-female joints to facilitate proper assembly.

The slicing operations were made with Cura software with these parameters: 0.4 mm nozzle, 0.15 mm fine detail level, and 15% infill. The fabrication, made by BQ Witbox 2 at UPV, took about six hours and a half, using 54 grams of filament (Fig. 8).

The material used is PLA, pearl brown colour for the preserved portion and white for the reconstructed ones so that they can be immediately identified (Fig. 9).

This type of replica represents a prototype that can be used for didactic purposes. The PLA is not an optimal choice for tactile experience because of the roughness of the layers that alter the surface and the object's weight. The tactile replica should be made of resin to make the experience more pleasant. With resin, the surface is smooth enough to allow blind and visually impaired people to perceive shapes, homogeneous and free from any epidermal alteration.

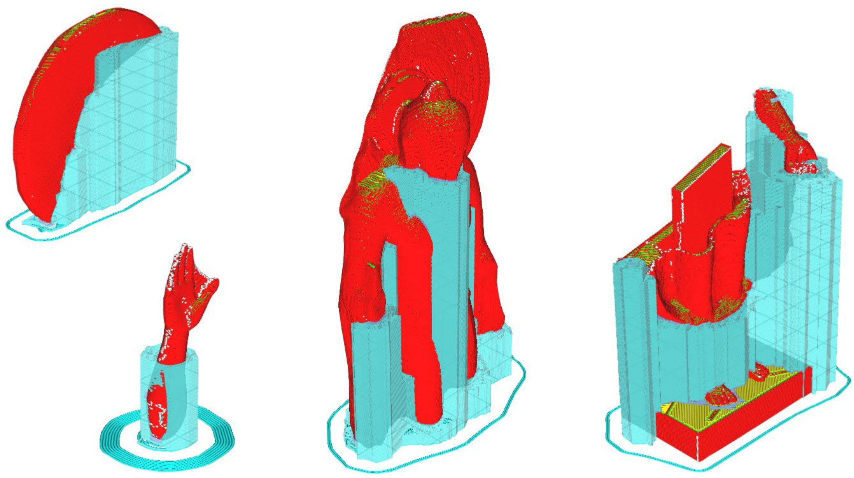

Fig. 8. De- composition of the statue model aimed at 3D printing. Processing: F. Ronco.

Fig. 9. Mounting of the physical replica. Processing: F. Ronco.

6 From 3D Modelling to AR Experience

The development of the AR experience went through several steps, from the SfM acquisition to the 3D modelling of the statue and the missing parts. The digital model was uploaded into the Model Target Generator, a Vuforia software that allows the creation of a 3D target from a model. This approach is called markerless, meaning that the AR experience does not use additional marker targets; instead, the camera recognises the statue itself. The purpose of the experience is to see the missing parts of the statue reconstructed, so a modelling phase was necessary, made possible by Blender's sculpting tools. Starting from a mesh of a human mannequin, it was positioned in the same pose as the statue through Pose Mode, trying to maintain continuity, especially with the arms and legs. Subsequently, using various brushes, the mesh was sculpted to match the body's style and add the missing parts of the robe and halo. To make the model lighter, the sculpted details were baked into a series of Normal Maps, reducing the number of polygons while simulating the same resolution.
The statue model and the reconstructed parts were then loaded into Unity's assets, the game engine used for the project. The Vuforia package was added to the project, allowing the previously created Model Target to be loaded. In the series of tools offered in the Vuforia menu, the AR camera was placed in the scene instead of the default camera. This type of camera, in combination with the presence of the model target, can recognise and track the target, overlaying Unity's virtual scene in the real world. To make the presence of virtual elements as realistic as possible, the same lighting situation inside the museum room was recreated by adding three spotlight-type light objects to the scene.

At this point, a scripting phase in C# was necessary to program user interactions and responses from objects in the scene. One tool used to make scripting more intuitive was Bolt, a plugin that converts script files normally handled in Visual Studio into visual scripts. Instead of writing lines of code, you use sets of nodes that connect various blocks, each representing a C# function or method. This makes scripting more intuitive and allows you to monitor the code's flow in real time during play mode. Each reconstructed part was equipped with a Mesh Collider component to make them visible to the Physics Raycaster. The Raycaster is a virtual ray programmed to start from the user's touch on the screen and proceed perpendicularly in the same direction. When the Ray hits certain types of objects, in this case, those with Mesh Colliders, it recognises them, and in the specially created script, it checks the tag of the specific object. For example, suppose the tag corresponds to the left arm. In that case, it activates the animation highlighting the left arm by changing the material's colour and triggering the corresponding audio track with its transcription in the expandable text panel. This operation was performed for each reconstructed part, adding a separate animation to show the two possible configurations of the right arm. All that is needed for the user to tap the screen at the location of one of the reconstructed parts they want to learn more about (Fig. 9).

Fig. 9. Screeshots from AR experience. Processing: L. Lombardi.

The other elements with which the user can interact belong to the User Interface. This is quite simple, as there are only a few very intuitive buttons inside the screen's Canvas: a button that displays the reconstruction, a pause/play button for audio playback, an arrow to return to the first section, and finally, the arrow that expands and collapses the text panel. Some simple operations are connected to the buttons through the default OnClick function, such as activating or deactivating certain objects.
Finally, to complete the experience, an image with the silhouette of the entire statue was added so that the users, once they open the app, knows from which angle to frame the artwork to start the experience. Once correctly framed, the silhouette disappears, a script displays the User Interface (UI), and makes the other interactions available.

7 Conclusion

As seen, the present experience is characterised by the circularity that characterises the continuum between real and virtual, beginning and ending with two physical entities: the artwork and its replica.

It is interesting to observe how the role and impact of information processing systems in the cultural heritage field have allowed the joining of different knowledge around digital reconstruction and its communication.

Different levels of interest in this approach emerge, highlighted within the scope of this research:

- the availability of visualisations and prefigurations that offer scholars the possibility of evaluating alternative hypotheses of philological reconstruction;
- the provision of tools that facilitate communication and interaction with the public, conveying content and proposing narratives in new ways;
- the possibility of implementing inclusive communication tools, including combining different devices and media.

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