Ethical Aspects of Digital Reconstruction of the Historical Cultural Heritage

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Abstract. Digital reconstruction of historical artefacts supports cultural heritage preservation, providing new insights beyond digitization. This study addresses ethical challenges of authenticity and interpretation when digitally restoring missing parts, analysing technical processes. Using concrete examples, it explores the interplay between ethical standards and technology in digitization and access to cultural heritage.

Keywords: Digital Technologies, Cultural Heritage, Digital Reconstruction, Digital Editing, Ethics.

1 Introduction

In recent years, there has been a significant development of digital technologies, which has brought new possibilities in the field of reconstruction of historical artefacts in digital form. This is especially relevant in the case of artefacts whose preservation is often very limited. Digitization using 3D technologies, such as 3D scanning and photogrammetry, allows for a faithful depiction of the actual condition of objects and their subsequent reconstruction. At the same time, however, ethical questions arise concerning the authenticity and interpretation of the supplemented parts of the artefacts.

Digital reconstruction works with damaged or broken artefacts, which, like classical restoration, are supplemented based on expert opinion and available historical references, e.g. in the form of photographs or drawings. This innovative approach to restoration in a digital environment poses ethical challenges in the form of possible distortion or, in extreme cases, falsification of historical reality. It is therefore essential to establish clear ethical principles that will define the limits of digital intervention.

This article is based on an analysis of the technical practices of 3D scanning, 3D modelling and photogrammetry of tangible cultural heritage, which are carried out in the light of contemporary documents and charters defining the possibilities and approaches to cultural heritage. The Centre for Digital Historical Sciences under the Philosophical Faculty of the University of Hradec Králové cooperates with various institutions, both for digitization and digital reconstruction for various purposes. So far mainly for popularization and educational purposes.

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The text also reflects the importance of interdisciplinary cooperation, where experts from IT and humanities together ensure that technological possibilities are not used at the expense of scientific and historical accuracy. The article was supported by the Specific Research 2025 of the Philosophical Faculty, University of Hradec Králové.

2 International Documents and Frameworks Governing Interventions in Cultural Heritage about Digital Space

The ethical principles of restoration and conservation of tangible cultural heritage are key to preserving their authenticity and value. International documents, such as the Venice Charter, The ICOMOS charter for the interpretation and presentation of cultural heritage sites, The NARA document on authenticity, the London Charter and the Faro Convention, provide a key framework for interventions in cultural heritage by providing standardisation of ethical principles, technologies and practices for the protection, restoration and presentation of historic objects. In the context of digital cultural heritage, these documents are particularly relevant as they respond to technological advances and new forms of preservation and access to historical artefacts (Rouhani, 2023).

In general, all documents and charters on cultural heritage aim to define the basic objectives and principles of interpretation (of sites, interventions, etc.) in relation to authenticity, intellectual integrity, social responsibility and respect for cultural significance and context. The Venice Charter (1964) established key principles of authenticity and minimal intervention in heritage sites, but its application in the context of digital technologies is limited due to the historical time of its creation. (International Council on Monuments and Sites [ICOMOS], 2024) The London Charter (2009) represents a shift towards digital technologies, emphasising transparency, documentation and clear interpretation of interventions. The Charter defines principles for the use of computer visualisation methods in relation to integrity, reliability, documentation, sustainability and access. It is now recognised as the de facto benchmark against which cultural heritage visualisation processes and outputs should be guided. (The London Charter, 2024) The emphasis on digital interventions in the Seville Charter (2011) extends the principles of the London Charter with an emphasis on the application of digital technologies, interdisciplinary collaboration and rigorous methodological transparency. The creation of the Seville Charter was supported by the need to clearly define the rules and methodology of virtual archaeology and digital reconstruction. (Lopez-Menchero & Grande, 2018).

Computer visualization has become an important tool for the investigation, conservation, interpretation and presentation of archaeological heritage. Projects focusing on this area have shown the potential of computer visualization, but also its shortcomings. There is a lack of theoretical discussion that would enable cultural heritage managers to make the best use of new technologies while minimizing their controversial applications. The Spanish Society for Virtual Archaeology (SEAV) is working with hundreds of researchers from around the world to develop an international document called the

Seville Charter, which should provide guidelines in this area. To achieve the most accurate 3D models of cultural heritage, it emphasizes the need for collaboration between experts across disciplines (e.g. archaeology, history, IT, graphic design, etc.). Digital reconstruction under the Seville Charter must be clearly identified as an interpretation based on available scientific knowledge, not as an unquestionable historical fact. (Lopez-Menchero & Grande, 2018).

Other relevant documents include the Nara Document on Authenticity (1994), which extended the concept of authenticity within cultural contexts. (Luxen & Magar Meurs, 2019). The Ename Charter (2008) emphasises the interpretation and presentation of heritage sites and explicitly sets out how interpretation is to be informed by scientific principles and transparent documentation. (ICOMOS, 2006). UNESCO Recommendations (2015, 2011) define standards for digital documentation, preservation and management of cultural heritage, responding to the need for quality digitisation of collections, (UNESCO, 2015) and the European Quality Framework for Action on Cultural Heritage (2018) specifies quality criteria and ethical standards for interventions in cultural heritage in the European context, with an emphasis on digital technologies. (Ministerstvo kultury ČR, 2019).

Although these documents provide a fundamental framework for the treatment of cultural heritage, they have their limits, especially in the context of rapid technological developments. For example, the Venice Charter can no longer respond adequately to the challenges posed by modern technologies such as virtual and augmented reality or artificial intelligence. The London and Seville Charters already incorporate this technological dimension, but these documents also require regular revision and updating to reflect the latest developments in digital technologies and new ethical dilemmas. In the future, it will be essential to continuously update the documents and broaden their scope, especially about machine learning, artificial intelligence and the possibilities of autonomous digital reconstruction and simulation. It is therefore clear that artificial intelligence and machine learning are now also important topics in the field of cultural heritage. The 2022 Study on the Opportunities and Challenges of Artificial Intelligence Technologies for the Cultural and Creative Industries explores, among other things, the challenges and opportunities that AI and related technologies bring to support and access the culturally diverse supply of European works. (European Commission, 2022).

3 Cases of Digital Reconstruction and General Interventions in 3D Models of Historical Artefacts

The key to successful 3D digital reconstruction of the historical artefacts is using the right technology, appropriate formats and data size. The methodology of digital reconstruction as applied in this study can be divided into three main phases:

1) Data acquisition through 3D scanning and photogrammetry,
2) Data processing and modelling using software tools such as Blender,
3) Interpretative reconstruction based on historical references and interdisciplinary consultation.

To obtain a 3D model of historical artefacts, we can use 3D scanning or photogrammetry technology. Another criterion is the purpose for which the historical object is digitized. It may be a scientific purpose, so it is necessary to provide as much data as possible to show the greatest detail. Another option is a popular educational purpose, e.g. promotion of a heritage area on a website and display of a 3D model on the web. Then the user experience and the possibilities for easy display by visitors and the public will be considered.

In the data acquisition phase, handheld scanners such as Artec Micro, Artec Space Spider, and Artec Leo (the property of the Center for Digital Historical Sciences) were employed to scan small-scale artefacts, while photogrammetry and drone imaging were used for larger outdoor monuments. The basic categorization of scanners is based on the size and nature of the object being digitized. Handheld 3D scanners (e.g. Artec Micro, Artec Space Spider, Artec Leo) have proven to be particularly useful for digitizing smaller a collection of artefacts such as the Náchod Museum's collection of historical clocks in 2020 but also seals and other objects that allow for easy handling. (Rybenská & Borůvková, 2020). For the digitization of oversized historical monuments in the exterior, such as statues, the Centre for Digital Historical Sciences uses mainly the method of photogrammetry. Alternatively, if these objects are easily accessible from the ground, an Artec Leo handheld scanner can be used. For even larger objects that are difficult to access from the ground, aerial photogrammetry, combining images taken by drone with photographs from the ground, has been successfully applied. (Rybenská et al., 2023).

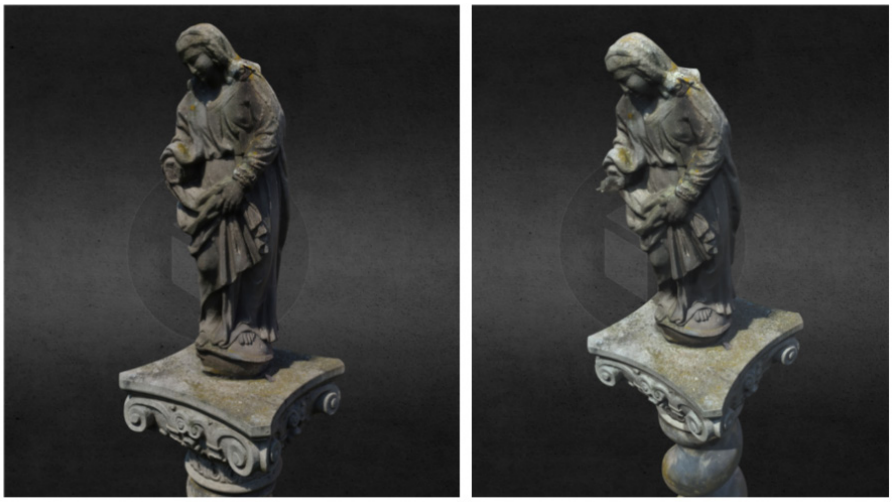

Fig. 1. Comparison of the 3D model of the original statue and the 3D model of the statue with the hand.

The members of the Centre for Digital Historical Sciences participated in the creation of 3D models of the sacral monuments in the Broumov region in the Czech Republic. The result is 4 models that are used by visitors to the site. The scientific team was

attracted by the column with the statue of the Virgin Mary in Hejtmánkovice, where the Virgin Mary did not have a hand. In cooperation with historians and conservationists and by searching for images of other similar monuments in the area, a reconstruction of the form of the hand that the statue had was created. 3D models are available on the website: https://pamatky.broumovsko.cz/3d-modely and https://sketchfab.com/KPVHA-FF-UHK/collections/broumovsko-7feef3216b2c490299f347de331314da

Interference with the 3D model can also occur when a historical artefact is not captured correctly.

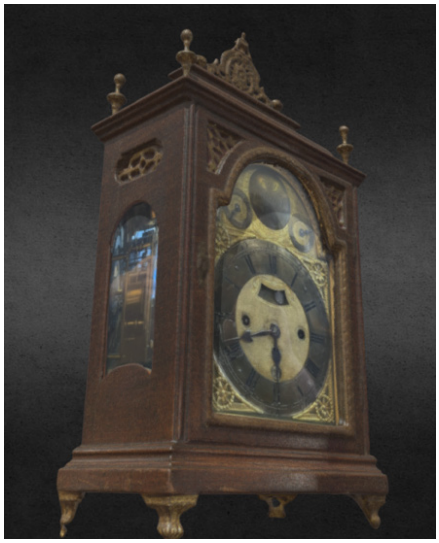

Fig. 2. Glass parts of the clock replaced by a photograph.

The above example already reflects several parts of the collection of historical clocks from the Náchod Museum whose glass parts were problematic for the 3D scanner. These parts were to some extent replaced by a photograph of the problematic part of the clock. (Rybenska, 2021). Another example is the part on which the historical artefact stands and will naturally be missing from the 3D model. For the sacral monuments in the Broumov region this was not addressed, as it was the lower base of the statue.

For artefacts such as seals, a problem may arise when it is necessary to create two models and then join them in the right places.

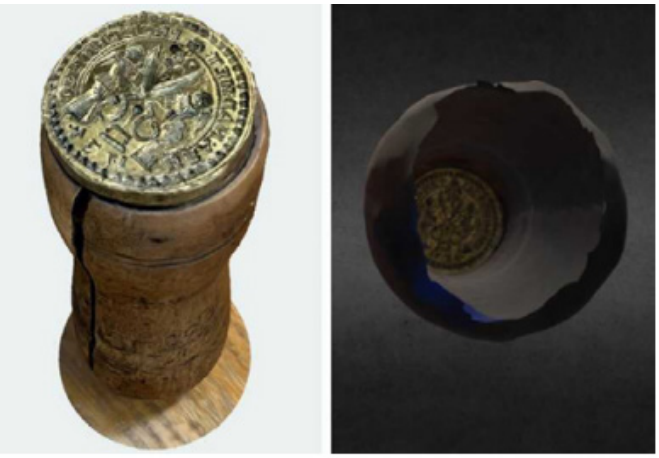

Fig. 3. Example of a missing polygon mesh in a 3D model of a seal.

The data processing phase included combining photogrammetric outputs and post-processing steps such as hole filling, mesh optimization, and correction of texture errors using software like Blender. This type of artefact can usually be photographed both horizontally and vertically, and it is optimal to create the obverse and reverse models separately in the selected program. The two sides can be combined in a program designed to create 3D models, such as Blender, or higher versions of photogrammetry programs that allow for more advanced features. In the case of typefaces, a similar procedure has proven successful. First create a model of the sealing surface and separate the handle and then join them together. During digitizing, errors can occur in the form of poorly mapped textures or holes in the polygon mesh of the model. Subsequent post-production in a 3D modelling program is necessary in 90% of cases. (Rybenská et al., 2023). Both photogrammetry and 3D scanning face difficulties in accurately digitizing specific object surfaces. This typically includes shiny, transparent or glossy black surfaces. Vegetation on a landmark, typically a historic statue outdoors, can also be a problem for 3D scanners. This is because shiny metal or glass surfaces often cause distortion in the resulting model. A suitable solution to this problem is advanced editing of digital models, which can be done, for example, using Blender software. With features such as texturing, retopology and sculpting, Blender is proving to be a suitable tool for the digital restoration of historical artefacts. In Blender, it is possible to accurately restore damaged or missing parts of artefacts, to retouch textures or to reconstruct lost fragments with the utmost concern for authenticity. In practice, digital restoration most often involves removing texture blemishes, filling in missing segments, and joining two parts in accordance with the original appearance of the object. (Garstki, 2017).

The interpretative reconstruction phase involved collaboration with domain experts to infer missing elements based on comparative analysis and historical documentation. The reconstruction projects carried out by the Centre for Digital Historical Sciences have demonstrated both the potential and limitations of current 3D technologies. In the case of the Virgin Mary statue in Hejtmánkovice, missing parts were reconstructed in

collaboration with historians and conservators, based on comparative visual materials. Similarly, issues encountered during the digitization of historical clocks, such as transparent surfaces or inaccessible parts, were addressed through hybrid solutions—combining 3D models with photographic overlays. These examples underscore the necessity of interdisciplinary approaches and the importance of transparently documenting all digital interventions applied during the reconstruction process.

4 Discussion and Conclusion

Digital reconstruction of historical cultural heritage presents unique opportunities for preserving, interpreting, and sharing fragile or incomplete artefacts with broader audiences. When responsibly conducted, these reconstructions can contribute to both scholarly knowledge and public engagement. However, they also raise persistent ethical concerns—particularly regarding authenticity, the boundaries of interpretation, and the transparency of digital interventions.

The integrity of digital reconstructions depends on adherence to internationally recognised charters, such as the London Charter and the Seville Charter. These frameworks emphasise methodological transparency, accurate documentation, and interdisciplinary collaboration. Yet the accelerating development of digital technologies—particularly artificial intelligence and machine learning—has outpaced the scope of existing standards and created new ethical grey zones.

Although no AI tool currently offers fully autonomous and contextually accurate reconstruction of missing parts in historical artefacts, several software environments now include plugins or functions that can infer missing geometry or texture data based on algorithmic predictions. These features, while technically useful, raise serious epistemological questions about the evidentiary status of such reconstructions—especially when AI-generated outputs will not critically be assessed or clearly marked. As Rouhani (2023) mentions, critical oversight is essential to prevent the unintentional falsification or oversimplification of historical realities.

Considering these developments, several ethical guidelines should be considered for future work with AI in digital reconstruction:

- All AI-generated elements should be subject to expert validation prior to dissemination or publication.
- Transparency mechanisms—such as embedded metadata, colour-coding of reconstructed areas, or layered model files—should clearly distinguish between original data and algorithmically inferred content.
- Open-access documentation of the reconstruction process should be standardised, regardless of the software used.

In parallel, future research should explore the ethical implications of open source versus proprietary software in digital heritage workflows. While open-source tools may foster greater transparency and community validation, they also raise questions about sustainability, technical support, and interoperability. Conversely, proprietary platforms often offer high-quality outputs but may obscure the logic behind AI-generated decisions or restrict access to modification logs.

An additional and underexplored challenge lies in the concept of layered authenticity—that is, the ability to recognise and document artefacts as multi-temporal objects that have undergone successive modifications or restorations. Digital tools must evolve to enable reconstructions that do not flatten historical complexity into a single "ideal" version, but rather offer ways to visualise, annotate, and compare different historical states of the same object. These considerations are not merely technical but touch on the epistemological foundations of how we construct and communicate knowledge about the past.

To ensure long-term trust in digital reconstruction as both a scholarly and public-facing practice, we must continue to invest in interdisciplinary dialogue, shared standards, and critical digital literacy. Only then can emerging technologies become a means of deepening our understanding of the past, rather than oversimplifying or distorting it.

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