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Recommended 3D Workflow for Digital Heritage Practices

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Abstract

This paper addresses the concerns of the digital heritage field by setting out a series of recommendations for establishing a workflow for 3D objects, increasingly prevalent but still lacking a standardized process, in terms of long-term preservation and dissemination.

We build our approach on interdisciplinary collaborations together with a comprehensive literature review. We provide a set of heuristics consisting of the following six components: data acquisition, data preservation, data description, data curation and processing, data dissemination, as well as data interoperability, analysis and exploration. Each component is supplemented by suggestions for standards and tools, which are either already common in 3D practices or represent a high potential component seeking consensus to formalize a 3D environment fit for the Humanities, such as efforts carried out by the International Image Interoperability Framework (IIIF).

We then present a conceptual high-level 3D workflow which highly relies on standards adhering to the Linked Open Usable Data (LOUD) design principles.

Motivation

While images still play an important role in industrial and scientific research, the challenge of storage and dissemination of digitized or native 3D images is gaining momentum and is now a very substantial part of the data that organizations and research projects generate. 3D data provides many opportunities for applications that can significantly contribute to knowledge transfer [1] and data analysis [2]. Yet the generated output files are extremely voluminous and not suitable for seamless viewing. To make matters worse, there is still no standard for archiving 3D objects [3]. Robust long-term preservation and dissemination strategies that address these issues are needed.

Thus, we aim to establish some common practices. We have firstly gathered empirical evidence for our recommended 3D workflow for digital heritage practices through interdisciplinary projects[1], where there is a lack of standardized process. Parallelly, we have thoroughly reviewed existing research, best practices, and case studies from the digitization, digital humanities, and GLAM (galleries, libraries, archives, museums) sectors to inform our recommendations. We are driven to establish such a workflow to support the preservation of digital heritage at large, to study 3D artifacts in new ways and to increase their accessibility, as well as to provide new opportunities for collaboration, notably by being inspired by the efforts of the International Image Interoperability Framework (IIIF) community [4,5], in which all we are active participants and advocates. Moreover, we want to create awareness for data quality.

We begin this paper with a rationale for a generic workflow based on existing practices in the humanities and archival research, followed by a brief literature review on 3D digital heritage practices. We then proceed with our recommendations and provide insights into perspectives and future work. Finally, we conclude our analysis.

[1] For instance, via the ongoing *Digitales Schaudepot* project: https://www.digitalesschaudepot.ch/

Rationale

Two recently published activity processes or research workflows caught our attention, and we take them as a source of inspiration because the first one is concerned with semantic interoperability aspects in an archival context [6] and the second heuristic is rather a generic workflow in the Humanities [7]. Both things are very close to what we do at the Digital Humanities Lab of the University of Basel where we have as much a digitization service for cultural heritage institutions as academic objectives.

Fafalios et al. [6] recognize the following six activities as common data management to enable semantic interoperability:

1. **Digitization / Transcription**: scanning of documents, text recognition, manual transcription
2. **Documentation / Metadata Recording**: what is the origin of a document, what is the document about, who makes the transcription, etc.
3. **Data Curation**: preparing the data for statistical analysis such as correction or normalization of data values, instance matching, term alignment, etc.
4. **Data Integration**: integration under a common representation language
5. **Data Publication**: for example, as Linked Data
6. **Data Analysis and exploration**: qualitative and/or quantitative analysis, query building, data visualization, etc.

With Waters [7], the focus is on an academic publication process and on outputs that are not necessarily intended to be manipulated via SPARQL for Linked Data or via RESTful application programming interfaces (APIs). Rather than activities, he outlines six functions (*Collect, Catalog, Transcribe/Translate, Identify, Analyze/Interpret, and Publish*) and gives examples of either tools or standards for each function within a research workflow (see Figure 1). Another critical difference with [6] is also in the transcription approach, which is a separate post-cataloguing step inside Waters' workflow.

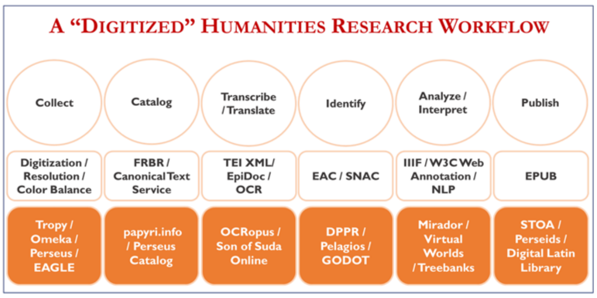

***Figure 1.** A "Digitized" Humanities Research Workflow by [7]*

In Table 1 hereafter, we have attempted to align the two heuristics with our components by taking the approach of Fafalios et al. for the digitization and transcription part while adding a long-term preservation component. Regarding the data integration, considering that we would like to be able to export the metadata in different outputs (Linked Data or not), we create a data dissemination component that includes two functions of Fafalios et al. (*Documentation / Metadata Recording* as well as *Data Integration*), which is somewhat equivalent to Waters' *Catalog*.

Table 1: Heuristics Alignment

N/A	N/A	Data preservation
Digitization / Transcription	Collect + Transcribe / Translate	Data acquisition
Documentation / Metadata Recording + Data Integration	Catalog	Data description
Data Curation	Identify	Data curation and processing
Data Publication	Publish	Data dissemination
Data Analysis and exploration	Analyze / Interpret	Data interoperability, analysis and exploration

Altogether, we obtain six components that are discussed in the next section. Even if, as shown on Figure 2, they have a certain natural sequence (from data acquisition to data interoperability, analysis and exploration), these components could also be carried out iteratively. We also want to illustrate with this diagram that it is the responsibility of memory institutions and academics to think of data description as an activity that should be pursued and revisited as soon as new knowledge is acquired and that data preservation is a transversal component. It should be noted, however, that the quality and depth of the collected data and related metadata are paramount for producing an optimal viewing experience and that it is preferable to begin with a high-quality scan or digital-born object since new material digitization or upscaling would often be very costly and time-consuming.

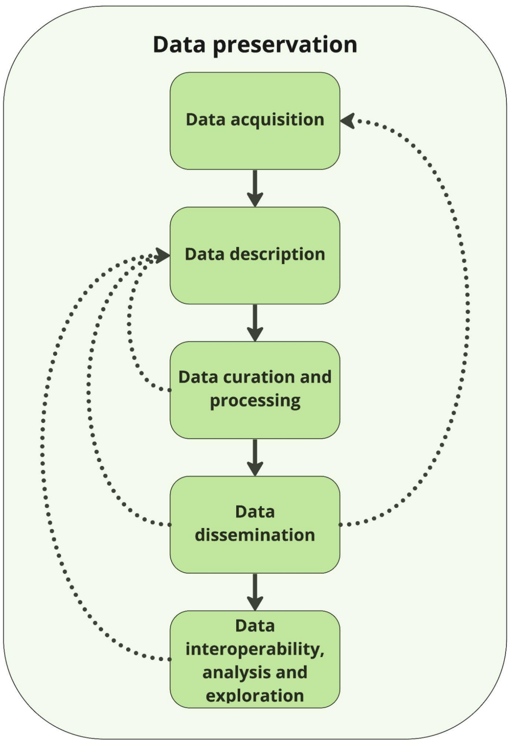

***Figure 2.** Overlaid 3D components for Digital Heritage Practices*

3D Digital Heritage Practices

Over the last decade, 3D digitization technologies have become an important part in the cultural heritage sector for the documentation and visualization of originals and spread beyond its main application area of archaeology [8,9] over to other humanities disciplines [10]. While large corporations such as Apple, Samsung, Huawei, or Meta strive to make the scanning and use of 3D objects via mobile apps as simple as possible for the mass consumer, professional 3D digitization methodology appears to continue to rely on long-established technologies such as Image-based modeling (e.g., SfM Photogrammetry and Multiview Stereo) or laser-, light- and LiDAR- scanners, as well as the associated, most of the time commercial software [11, p. 31][2] The dependency on established technologies made it possible to evaluate the methods for a wide range of applications and to develop best practices for the practical digitization process, which are aimed at achieving an optimal result with regard to the prerequisites of the respective technology [13,14,15,16,17,18].

While general guidelines, to ensure a certain quality standard of the models, seem to establish themselves for the practical digitization of an object, there isn't such a widespread agreement when it comes to digital asset management (DAM). Handling data formats, metadata, long-term archiving and (online) publication is still done individually, despite numerous recommendations and standards made over the last decade [19,20,21,22,23]. According to the "Study on quality in 3D digitization of tangible cultural heritage" published by the European Commission in 2022, 30% of the participants reported collecting no metadata and 65% no paradata. At the same time, most respondents are not using recommended standards (e.g., LIDO, CARARE 2.0, Dublin Core), but their metadata schema, if using one at all [11, p. 32]. Although visibility and usability should be a basic requirement for research data, Champion and Rahaman [24] have shown that in 264 scientific publications referring to or containing 3D data of cultural heritage, only in nine cases was the model accessible for download. In nineteen cases an external web link was given to look at the models, none of them worked.

The 3D workflow presented in this paper cannot, of course, solve the aforementioned challenges of the diversity in dealing with 3D cultural heritage data, but is a recommendation based on the practices of handling 3D objects in the Digital Humanities Lab of the University of Basel.

In Table 2, we summarize the activities of a 3D workflow and our recommendations for appropriate or potential standards and tools, i.e., software or service, that we suggest. We then discuss each of these activities in more detail.

Table 2: 3D workflow components and suggestions of appropriate or potential standards and tools

Activity	Suggested examples of standards (S) and tools (T)
Data acquisition	metamorfoze (S) FADGI (S)
Data preservation	OAIS Reference Model (S)
Data description	CARARE 2.0 (S) CIDOC-CRM / Linked Art (S)
Data curation	Smithsonian Cook (T) OpenRefine (T)

[2] This is primarily due to the level of development of the technologies built into the mobile devices used to date, which are already demonstrating initial promise but remain far from an application in cultural heritage digitization, particularly in concern to quality and accuracy of the created models [12].

and processing	
Data dissemination	Sketchfab (T) Morphosource (T) Smithonian Voyager (T)
Data interoperability, analysis, and exploration	IIIF (S) Web Annotation Data Model (S)

Data acquisition

In the context of practical 3D digitization methods of cultural heritage, no standards have been established so far, apart from some hands-on guidelines by cultural heritage institutions and equipment manufacturer specifications, especially when it comes to 3D scanning devices. However, in the context of photogrammetry, which is based on image source data, existing standards for 2D digitization such as “Federal Agencies Digital Guidelines Initiative” (FADGI) [26] or Metamorfoze [27] can be used to ensure quality control from the beginning.

FADGI, based in the US, provides various guidelines for the 2D digitization focusing on images and audio-visual data, ensuring the original's accuracy, integrity, and fidelity. Within the so-called “Performance Levels” in the FADGI Star System (1-4 stars), four quality levels are categorized and defined for different imaging tasks, each of them describing the technical requirements that an image file must meet. Metamorfoze takes a similar approach with its guidelines using a three-level quality ranking. The guidelines originate from preserving paper cultural heritage and are a product of the collaboration of the National Library of the Netherlands (Koninkliijke Bibliotheek) and the National Archives. Their suggestions mainly refer to the practical image capturing and technical metadata of the “preservation master”, i.e., the first image file.

Both standards can ensure high-quality images of cultural heritage objects, including during image capturing, to create input data for image-based modelling software. Looking at such guidelines for 2D photography is relevant because the images generated are the starting point for many 3D pipelines. In this respect, the quality of a 3D model generated in this way is largely dependent on the source material used. The recommendations made for 2D photography can also be adopted for 3D models, as they ensure a level of quality in the primary acquisition process.

Data preservation

This component is particular because it transversally encompasses all the others. We envision this data preservation component similar to the Reference Model for an Open Archival Information System (OAIS) which is intended for the management, archiving and long-term preservation of digital records. It is an ISO Standard (ISO 14721) that. There are six functional entities (*Ingest, Archival Storage, Data Management, Administration, Preservation Planning*, and *Access*) within OAIS as well as three information packages (*Submission Information Package, Archival Information Package,* and *Dissemination Information Packag*e).

Moreover, OAIS “*identifies the necessary features of an archival information system rather than recommend any particular implementation*” [24], i.e., there are a range of OAIS-compliant repositories which should provide their policies and procedures to carry out the different functions, the technological requirements for storing and converting files as well as the costs associated with the implementation of the standard.

Data description

Semantically, it seems to us a good solution for 3D objects to be asserted with CIDOC-CRM — a high-level ontology to enable information integration for cultural heritage data [28] — and more particularly though the RDF application profile of Linked Art[3], which also relies on JSON-LD as a serialization format as well as the Getty vocabularies[4] (AAT, ULAN, TGN) for finer classification of entities and their underlying qualities [29]. In our opinion, Linked Art has all the potential to be a generic 3D data description as it is use-case based and maintained by a community concerned with the needs of both scholars and developers [30]. Furthermore, Linked Art should facilitate the data to be interoperable, offering for example a RESTful API according to different top-level entities or endpoints (*Concepts, Digital Objects, Events, Groups, Physical Objects, Places, Provenance Activities, Sets, Textual Works, Visual Works*).

More specifically, “Connecting Archaeology and Architecture in Europe” (CARARE)[5], an aggregator of Europeana, has devised its own metadata scheme (CARARE 2.0) that is compatible with the Europeana Data Model (EDM) and based on LIDO, MIDAS, as well as CIDOC-CRM [22]. The current metadata scheme version is well suited for 3D archaeological data offering a rich vocabulary and relying, like Linked Art, on the AAT vocabulary.

Data curation and processing

Considering the data curation and processing part as much as a pre-production step as a post-publication process, we present here first a system for the creation and management of 3D objects, and then a tool for the cleaning of metadata that can also be used beyond the 3D context.

We would first like to point out what the Smithsonian has developed and maintained for generating 3D resources. They have created a comprehensive 3D asset management pipeline called the Smithsonian Cook[6], which is a Node.js-based server which can operate from file ingestion to publication through derivative file creation, i.e not considered to be permanent parts of an archival collection and produced for dissemination purposes, and content authoring. Open-source options are always available, but they come with some limitations for a few microservices. Within this pipeline, there are two main components which are *Cook* that automates the processing of the jobs (e.g., format conversion, meshing, texture, etc.) either through a Web user interface or an API as well as *Voyager* that is used for creating context around 3D objects and for quality control[7]. One of the very important features of the Smithsonian Cook is that reverse engineering is also possible to recreate derivatives or create new ones from master files according to new techniques or recommendations.

Another interesting software — especially in the preparation of metadata — would be OpenRefine[8], a data curation tool widely spread in the academic and cultural heritage fields, especially for data cleaning and reconciliation purposes.

Data dissemination

There are many commercial and institutional platforms and 3D web viewers to publish 3D models online[9]. Champion and Rahaman surveyed in 2020 comparing commercials with

[3] https://linked.art
[4] https://www.getty.edu/research/tools/vocabularies/
[5] https://www.carare.eu/
[6] https://smithsonian.github.io/dpo-cook/
[7] *Voyager* is also the name of their 3D viewer.
[8] https://openrefine.org/
[9] For an up-to-date overview of the major commercial online platforms, see Frey on All3DP: https://all3dp.com/1/free-3d-models-download-best-sites-3d-archive-3d

the well-known institutional heritage repositories and their options for sharing and displaying 3D data [31]. It is alarming to see how institutional repositories fare compared to commercial platforms, most of which do not specialize in cultural heritage. Hardly any of the research dedicated platforms offer, in addition to the possibility of downloading, a viewer with which the model can be interacted with, which is a crucial step in making the objects visible.

Probably the most mature viewer is the one of Sketchfab[10], which allows basic metadata, textual annotations as well as linking images. A measurement tool was introduced in Sketchfabs Labs Experiments in 2017[11], but has unfortunately not yet been integrated into the standard viewer. Many large museums such as the British Museum[12], digitization organizations, e.g., CyArk[13] and even institutional repositories are hosting their 3D on/or collaborating with Sketchfab, like "Share3D"[14] a collaboration with Europeana.

Next to Smithonian Cook, the 3D program at the Smithonian also developed another tool: Smithonian Voyager[15], a 3D web viewer, which can be used to either embed models of Smithonian on a website or to display own models within a custom-built viewer. Using the "Voyager Story Standalone[16]" web interface, 3D scenes with the integration of GLTF/GLB models, annotations, images, videos, audio and more can be easily constructed and downloaded to be implemented in HTML code.

A research focused repository for 3D data is MorphoSource[17]. Currently runned by the Duke University of Arts and Sciences it is a "*[...] web archive for digital data representing the internal and external 3-D geometry of physical specimens*" [32] – however cultural heritage data is also permissible. The wide capabilities entering metadata, as well as the creation of a Digital Object Identifier (DOI) for the uploaded data, are significant advantages compared to other 3D platforms.

3DHOP[18] - the 3D Heritage Online Presenter is an open-source framework, based on Javascript/SpiderGL, offering customizable 3D viewer solutions specifically for cultural heritage data, which can be implemented directly using HTML and JS even by non-expert developers. Initiated by the Visual Computing Lab of the ISTI-CNR in Pisa, 3DHOP early considered the need of CH-professionals to have the ability to show and interact with high-quality models online [33,34].

Data interoperability, analysis, and exploration

This component is not yet standardized but could well be streamlined thanks to the efforts of the IIIF community, which is in discussion with different actors of the 3D sector [35].

If the focus within IIIF was first in the dissemination of two-dimensional images and then audiovisual resources in a subsequent phase, there have been discussions and experiments for many years to expand the so-called *Shared Canvas* [4,36] or transform it into a space that can accommodate 3D objects. It is one of the purposes of the IIIF 3D Technical Specification Group[19] to specify a future Presentation API or an extension that can standardize this new framework that can display and annotate — which would be compliant to the Web Annotation Data Model as well [37] — as well as combine 3D resources with other media types in the same space and in an interoperable way.

High-level recommend workflow

The process we describe in Figure 3 is that of a 3D environment based on the standards and tools of each of the six components and presented in a high-level workflow that highlights the specifications adhering to the Linked Open Usable Data (LOUD) design principles[20] which are the following:

A. The right abstraction for the audience
B. Few barriers to entry
C. Comprehensible by introspection
D. Documentation with working examples
E. Few exceptions, instead many consistent patterns

IIIF APIs, Linked Art and the Web Annotation Data Model are specifications that adhere to these design principles, and all rely on JavaScript Object Notation for Linked Data (JSON-LD) as their serialization format and are all well-suited for cultural heritage data [38]. With respect to IIIF, it will still take some time before it becomes a realistic option for formally embedding 3D objects. And as a substitute or equivalent to the IIIF Image API for 2D images, we imagine that a service such as the Smithsonian Cook could take a leading role in creating, either manually or on the fly, derivatives that are compatible with both IIIF viewers and 3D viewers and repositories such as Voyager or MorphoSource.

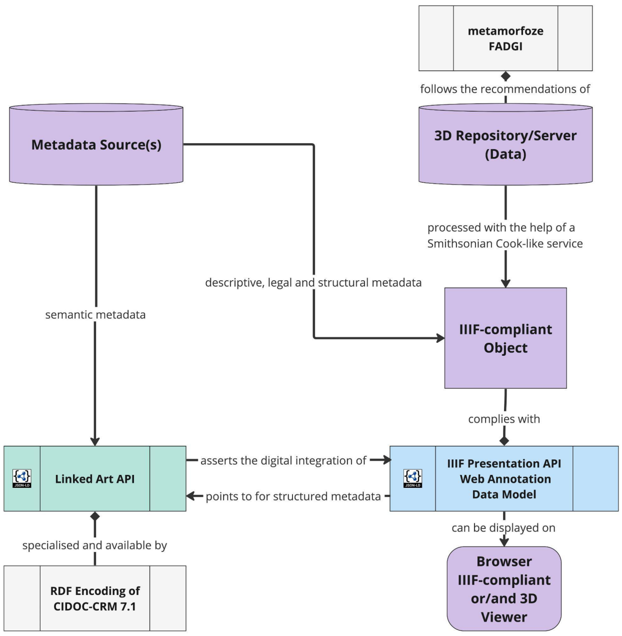

Figure 3. *Our Recommended 3D Workflow for Digital Heritage Practices that highly relies on LOUD standards. This diagram is a conceptual workflow considering what a suitable pipeline could look like once 3D has been formally specified by a future version of the IIIF Presentation API.*

[10] https://sketchfab.com/
[11] https://labs.sketchfab.com/experiments/measurements/
[12] https://sketchfab.com/britishmuseum
[13] https://sketchfab.com/CyArk/models
[14] https://share3d.eu/
[15] https://smithsonian.github.io/dpo-voyager/
[16] https://3d.si.edu/voyager-story-standalone
[17] https://www.morphosource.org/
[18] https://3dhop.net/
[19] https://iiif.io/community/groups/3d/tsg/
[20] https://linked.art/loud/

Perspectives and Future Work

3D data is becoming increasingly important in various areas of research because it can provide a realistic image of three-dimensional objects and scenes. This is especially relevant for fields such as archaeology, engineering, architecture, medicine, in game development, virtual realities and augmented reality. This of course also relates to the field of humanities.

3D data enables different stakeholders to have a common understanding of objects and scenes. This is particularly relevant for collaboration and participation in developing research in all topics where the originals are not easily accessible. Also, storytelling has a significant profit from 3D visualizations. Visualizing artifacts allows us to explore surfaces, understand the context and get an insight into hidden parts of our cultural heritage.

Standardization is especially important for 3D data in this context because it ensures that 3D models and data can be read and displayed by different software systems and devices. Without standardization, 3D data might not be interoperable between different applications and systems, resulting in limited use.

Today's computers and mobile devices can display even complex 3D models smoothly. The performance of graphics processors has increased enormously in recent years, so even smartphone applications that were only conceivable on special workstations some time ago are possible.

However, data networks are insufficient for volumes of 3D objects. For this reason, the dynamic loading of models will be further developed in the future. Dynamic loading is prevalent in the gaming world. Technologies from there will also be used for research in the future. The rendering of textures will also improve significantly. Today's textures still look synthetic and lack good lighting models that can authentically represent complex surfaces.

Regarding the standardization of dissemination and annotation of 3D objects, IIIF plans to pursue ongoing discussions through its two dedicated 3D groups: the Community Group to raise awareness and carry out demos and the Technical Specification Group to prepare future milestones for the API. In addition to these monthly and online conversations, face-to-face meetings are also planned, either at annual conferences (June 2022 in Cambridge, MA, USA and June 2023 in Naples, Italy) or ad-hoc meetings as it will be the case in Basel, Switzerland in October 2023 where we will organize a joint 3D event and workshop with DaSCH - Swiss National Data & Service Center for the Humanities[21] and the IIIF consortium.

We understand that our high-level workflow for 3D objects based on specifications not yet fully standardized for 3D remains at a very conceptual level, but seeing the success that IIIF has had for 2D images and audiovisuals, we believe that it has the potential to have an extensive impact on 3D for Digital Heritage Practices.

Conclusion

In the field of images and text, different standards and workflows have already been established. IIIF, for example, is important for interoperability to merge images from different sources. In the area of 3D data, this integration is still largely missing. For this reason, best practices must be documented and shared in communities. Only in this way can the exciting and innovative aspects of 3D data be further developed and improved.

The domain of 3D is particularly challenging because, on the one hand, the already well-established approaches from data acquisition, preparation and dissemination can be applied. The rather young form of 3D data in the Humanities is also challenging. Already the generation of 3D objects is far more complex than in the case of 2D images. The individual tools are available, often as open-source programs, but the components are not streamlined. Therefore, various manual or semi-automatic intermediate processes are necessary to get the data in shape.

It is one of these aspects where the dialogue between peers is essential. It requires a new form of interdisciplinarity to make technology, tools and digital infrastructure prepared for handling 3D data sets. It is an important signal of large standardization communities, like IIIF, and memory institutions like the Smithsonian, that they work in this field and develop the standards of tomorrow.

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