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Data
Interactive Technologies, Digital for Culture and Education

Expert Group on Digital Cultural Heritage and Europeana

Basic principles and tips for 3D digitisation of tangible cultural heritage for cultural heritage professionals and institutions and other custodians of cultural heritage

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INTRODUCTION

In the 2019 Declaration of Cooperation on advancing the digitisation of cultural heritage, 27 European countries[1] have called also on the European Commission's Expert Group on Digital Cultural Heritage and Europeana (DCHE Expert Group) to contribute to the development of common guidelines for comprehensive, holistic documentation of European 3D cultural heritage assets.

As part of their contribution, the DCHE Expert Group, using also input from other external experts as mentioned in the Acknowledgments section, has drawn up a list of basic principles and tips for 3D digitisation of tangible cultural heritage.

The list of basic principles and tips below is especially for cultural heritage professionals and institutions, and other custodians of tangible cultural heritage, including local and regional authorities, who are in charge of cultural heritage buildings, monuments, or sites, who do not have any experience with 3D digitisation yet, neither directly nor via an external service provider. At the same time, it is also for all other such professionals, institutions and authorities, who may find here useful new principles or tips to help them in achieving the best results in 3D digitisation projects.

[1] 25 Member States (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Estonia, Finland, France, Greece, Hungary, Italy, Ireland, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden), and Norway and the UK

This list is a living document that will be updated whenever necessary, and any suggestions for changes or additions would be very much welcome at CNECT-DCHE@ec.europa.eu

PRINCIPLES AND TIPS

This list contains 10 basic principles for 3D digitisation of tangible cultural heritage, and a number of tips for each of them. You can find more details and advice by following the 'Read more…' link at the end of each section.

The basic principles at a glance

1. Consider the value of and need for 3D digitisation
2. Select what to digitise and for what use cases or user groups
3. Decide whether to digitise in-house or outsource
4. Clarify copyright aspects and plan for open and broad access
5. Determine the minimum quality needed, but aim for the highest affordable
6. Identify the different versions and formats needed for the different use cases targeted
7. Plan for long-term preservation of all data acquired
8. Use the right equipment, methods and workflows
9. Protect the assets both during and after digitisation
10. Invest in knowledge of 3D technologies, processes and content

1. CONSIDER THE VALUE OF AND NEED FOR 3D DIGITISATION

- 3D digitisation is valuable for many purposes, including conservation and preservation, reproduction, research, education, exploration, and creative or tourism-related reuses.
- 3D digitisation is a necessity for tangible cultural heritage at risk, for preservation and restoration purposes.
- 3D digitisation can provide virtual access to cultural heritage that is difficult to access or inaccessible, e.g. underwater.
- 3D digitisation can broaden access to cultural heritage for persons with visual impairments, by contributing to the creation of accessible tactile experiences.
- 3D digitisation can contribute to better protection of physical cultural heritage sites and objects by enabling research or discovery using 3D models instead of direct handling.
- However, 3D digitisation itself does not prevent risks to cultural heritage, and it is by no means a replacement of physical preservation.
- Furthermore, 3D digitisation by itself does not imply digital preservation in the

long term.

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2. SELECT WHAT TO DIGITISE AND FOR WHAT USE CASES OR USER GROUPS

- Define the rationale or purpose(s) of your 3D digitisation project.
- Focus on cultural heritage that is at risk or has high re-use value in digitised form.
- Consider the target user group(s) for whom you would digitise and how they would use such content.
- Examine the features of what you would digitise.
- Different use cases require different equipment and digitisation strategies, and different minimum quality levels.
- Involve non-digitisation departments, such as communication, education, or conservation, in co-designing and following up the digitisation project.

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3. DECIDE WHETHER TO DIGITISE IN-HOUSE OR OUTSOURCE

- Evaluate your in-house 3D digitisation capabilities. What human resources, skills and equipment are available in-house? What additional resources or training would be necessary?
- Carry out a cost-benefit analysis to consider whether in-house digitisation or outsourcing offers the best value for your project.
- Consider also how easy or difficult it would be to upgrade an in-house 3D work environment, and the availability of support and learning materials for the different 3D digitisation methods.
- Persons who deal with 3D digitisation, including especially when outsourcing, must have the capacity to understand the limits of different 3D techniques as well as to analyse and judge the results.
- When outsourcing, seek technical advice from 3D experts with specific experience in the area of cultural heritage and use 3D digitisation service providers with specific experience in working with cultural heritage or in other similar or relevant areas.

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4. CLARIFY COPYRIGHT ASPECTS AND PLAN FOR OPEN AND BROAD ACCESS

- Identify the rights applying and the individuals and organisations holding them, and engage in discussions with them prior to starting the digitisation.
- Define the copyright that is compatible with the identified rights, and that would be most suitable for the purpose(s) for which the digitisation takes place.
- Follow and encourage adherence to the principle that what is in the public domain should remain in the public domain after digitisation.
- Integrate licensing and copyright provisions into your access and re-use agreement, and include such copyright information in the metadata.
- When outsourcing, ensure that the call and contract require that any copyright

(or associated rights), including for metadata, be transferred to the beneficiary institution or released into the public domain, and not reserved by the service provider.

- Plan from the beginning how the 3D collection will be made available to your target users.
- Provide broad public access, storing and distributing 3D models via open public platforms as well as self-hosting.
- Ensure the content is also available in open formats, in order to prevent vendor lock-in or restrictive re-use.
- Include the metadata captured as machine-readable interlinked data (Linked Open Data), in order to enhance findability.

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5. DETERMINE THE MINIMUM QUALITY NEEDED, BUT AIM FOR THE HIGHEST AFFORDABLE

- Quality in 3D digitisation of cultural heritage is not only about capture accuracy and resolution, but also about other key aspects such as historical accuracy, range of data and metadata generated and collected, and fitness for purpose.
- Investigate how high the capture accuracy and resolution could be, what the costs are (in time and money), and the equipment, software and skills needed.
- Determine what the minimum quality necessary is for the target users and the way they use the content, and whether the project budget and timescale permit capturing at a higher level of accuracy.
- Aim for the highest 3D capture quality for the largest number of assets that the budget and time available allow.
- What is high model quality today may become just standard in the near future, and high-accuracy and high-resolution raw data may be useful in the future to generate new, better 3D models.
- Collect, generate and include rich metadata and annotations throughout the workflow (during digitisation, processing, visualising).
- When outsourcing, specify from the beginning what the quality requirements are, which rights apply, and what data in which formats the external provider has to deliver.
- Keep in mind that, regardless of how high the quality of digitisation, a 3D model is not a 100% exact copy of the original subject.

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6. IDENTIFY THE DIFFERENT VERSIONS AND FORMATS SUITABLE FOR THE DIFFERENT USE CASES TARGETED

- Purposes such as preservation and reconstruction require high-quality geometrically correct 3D models, while for visualisation or VR and AR applications, optimised decimated 3D models are more suitable.
- Use the raw data to produce a master high-resolution 3D model, which would serve as the basis for decimation and conversion into different formats to serve different purposes.
- Make the content available in multiple formats, of which at least one should be

an open format.

- Follow standards and best practices, and choose open and/or commonly used formats for 3D models, such as glTF, X3D, STL, OBJ, DAE, PLY, WRL, DICOM or IFC.
- Choose a viewer/platform for delivery that works on a range of devices and which can also be supported in Europeana.

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7. PLAN FOR LONG-TERM PRESERVATION OF ALL DATA ACQUIRED

- Making 3D content accessible online or otherwise does not equal archiving or long-term preservation, not even when doing multiple backups.
- Take into consideration long-term preservation from the beginning, including all aspects such as formats, storage, future migrations and re-use, ongoing maintenance and the corresponding long-term costs.
- Keep as much data as possible from the 3D digitisation process, depending on the storage and data management capabilities available, including the raw data.
- Select an archive that is able to accept the incoming digital data files, has the necessary storage space, and can offer a preservation service.
- Use and support as much as possible open file formats, software and hardware, and consider archiving also the software and any other system needed to open the files.
- Log and store all metadata collected, including the paradata about the digitisation process, and all the different versions of the 3D model generated for various uses.
- Put in place a data management system that tags all data, in order to make it easy to store and research the data.

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8. USE THE RIGHT EQUIPMENT, METHODS AND WORKFLOWS

- The equipment and methods used have to match the category of cultural heritage involved and the quality needed for the purpose of the digitised assets.
- The size and characteristics of the target, the intended uses, the logistical aspects, the budget available, the timing and the environmental conditions all have an influence on the choice of equipment and methods.
- Carefully evaluate equipment outputs. What may be suitable for movable tangible assets (e.g. museum objects) may not be sufficient for immovable cultural heritage (e.g. buildings, monuments or sites).
- Photogrammetry is suitable for materials such as stone, wood, concrete, textile, plastic, or metal (matte surface), but not for shiny, transparent or highly glossy objects, nor for objects with loose/movable parts.
- For complex objects, both the work performed on site and the data processing last longer, and the work schedule should consider those.
- The use of drones, for 3D digitisation of buildings, monuments or sites, often requires a drone pilot license and specific authorisations.

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9. PROTECT THE ASSETS BOTH DURING AND AFTER DIGITISATION

- Regard physical conservational aspects as part of risk management during digitisation.
- Carry out a preliminary study or analysis to determine the potential impact/damage of the technique used.
- Specify from the beginning of the digitisation project who would handle the cultural heritage assets, and who may come close to them.
- Make sure that any person handling the cultural heritage assets or operating any moving 3D digitisation equipment is competent to do that.
- Have professional conservators oversee the handling of objects, and involve them from the planning stage.
- Ensure that appropriate insurance coverage is in place.
- After digitisation in 3D, avoid as much as possible direct handling of the assets in question, using instead the digital twins created.

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10. INVEST IN KNOWLEDGE OF 3D TECHNOLOGIES, PROCESSES AND CONTENT

- Using 3D technologies to document tangible cultural heritage is gradually becoming more commonplace, and knowledge of such technologies and processes is becoming increasingly more valuable.
- Knowledge of 3D technologies, processes and content is valuable regardless of whether you digitise in-house or outsource.
- Acquire at least basic understanding about 3D, including technical requirements.
- When engaging directly in 3D digitisation, begin with a limited scope and a limited number of assets to acquire knowledge.
- Outsourcing of 3D digitisation, too, requires an understanding of the technologies, processes and content involved.
- Training courses on 3D for cultural heritage or on 3D technologies more generally are also available online via the major e-learning and other platforms.
- If you produce learning material and/or documentation on different aspects of 3D digitisation, make that content available under fully open licences that permit re-use for commercial and non-commercial purposes.

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OTHER REFERENCES AND RESOURCES

Final report of the 3D Content in Europeana task force

Guidelines providing an introduction to the 3D workflow, from data capture and processing to publishing your models online, prepared by EU-funded project 'Share 3D'

Guidelines and case studies on all technical and logistic aspects to create 3D models of cultural heritage objects (3D data capture techniques, post processing of 3D content, 3D publishing methodology, metadata, and licensing and IPR considerations), by EU-funded project 3D-ICONS

Video training course on 3D for cultural heritage, by Visual Dimension bvba

Learning 3D tutorial by Sketchfab, in three parts: Simple geometry, Adding color, texture & light, and Create your own models

3D Scanning Software and 3D Modelling Software, by Sketchfab

How to set up a successful photogrammetry project, by Abby Crawford (Archaeological Graphics) on Sketchfab

GLAM 3D Open Access introduction and reference to the digital 3D content creation process

Examples of innovative digital experiences of cultural heritage, including cases that involve 3D content - Cultural Heritage @home

Guide on tactile accessibility and how 3D-printing is one technology that can support tactile accessibility

Europeana Public Domain Charter

London Charter for the Computer-based Visualization of Cultural Heritage

Smithsonian 3D Digitisation

READ MORE

1. CONSIDER THE VALUE OF AND NEED FOR 3D DIGITISATION

- 3D digitisation is valuable for many purposes, including conservation and preservation, reproduction, research, education, exploration, and creative or tourism-related reuses.
- 3D digitisation is a necessity for tangible cultural heritage at risk, for preservation and restoration purposes.
- 3D digitisation can provide virtual access to cultural heritage that is difficult to access or inaccessible, e.g. underwater.
- 3D digitisation can broaden access to cultural heritage for persons with visual impairments, by contributing to the creation of accessible tactile experiences.
- 3D digitisation can contribute to better protection of physical cultural heritage sites and objects by enabling research or discovery using 3D models instead of direct handling.
- However, 3D digitisation itself does not prevent risks to cultural heritage, and it is by no means a replacement of physical preservation.
- Furthermore, 3D digitisation by itself does not imply digital preservation in the long term.

Tangible cultural heritage that is suitable for 3D digitisation includes (1) immovable tangible cultural heritage (e.g. buildings, monuments and sites), and (2) movable tangible cultural heritage (e.g. museum objects and other similar artefacts).

3D digitisation of tangible cultural heritage is valuable for conservation, analysis and research, access, education, tourism, and creative reuses. In the case of tangible cultural heritage that is at risk, 3D digitisation is a necessity, for preservation, conservation, material analysis, and restoration purposes. Such risk may come from sudden events, e.g. disasters or theft, or from more long-term or continuous processes, e.g. climate change or the continuous use and natural decay of materials.

Sometimes, authorising the repurposing of land for new uses may lead to the destruction of archaeological remains. Such examples include excavations carried out prior to the construction of roads, airports, or housing. Archaeological remains may be destroyed and disappear below these constructions. 3D digitisation would be very important for documenting archaeological remains (or archaeological sites) in such cases.

At the same time, 3D digitisation also creates new, rich possibilities for increasing the exposure of cultural heritage and re-using it in various applications for different sectors, including in particular education, the cultural and creative industries, and tourism. Where the risk of deterioration or destruction is low, the main reason for digitisation is the value of the cultural heritage assets in question, including for re-use.

3D digitisation is also important where access is limited or impossible. For example, underwater cultural heritage is especially exposed to a wide range of risks, and knowledge of such sites is often limited because of their inaccessibility. According to the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage, conservation of such heritage takes place mainly in situ. 3D technologies could give an opportunity to get closer to this type of heritage in a remote, virtual way. Similarly, 3D technologies could be an important option to access all spaces also in the case of other special types of museum, such as house museums. Another situation where such technologies can improve access is where cultural heritage assets are spread to many different places, such as in the case of collections of objects, or Egyptian monuments.

At the same time, in the case of persons with visual impairments access to tangible cultural heritage requires a tactile experience. Such experience is not always possible, given that many objects or sites are not available to touch. 3D digitisation can make tangible cultural heritage more accessible to persons with visual impairments, by contributing to the manufacturing of physical replicas conveying the experience both of shape and volume and of textures and materials.

Digitisation in 3D can help to ensure better protection of physical cultural heritage sites and objects by making 3D models available for research or discovery, and thus limit direct handling. Furthermore, 3D digitisation could be an important mean of research and preservation of cultural heritage. 3D measurements can be a basic tool for monitoring the state of cultural heritage elements, their possible degradation from both anthropogenic and natural causes and related maintenance, conservation and restoration actions. It could anticipate the impact of functional interventions or of mobility of cultural property. 3D digital twins could allow re-assembling dismembered archaeological contexts or fragments of an individual object, identifying stolen objects, etc.

However, 3D digitisation itself does not prevent risks to cultural heritage. 3D models could be used to accurately document originals, to enhance research and monitoring, to replace access to fragile originals, to offer digital copies when the original is lost, thus, of course, contributing to preservation of the actual objects. Nevertheless, digitisation is by no means a replacement of physical preservation, and should not lead to lower preservation standards.

Furthermore, 3D digitisation by itself does not imply digital preservation in the long term. 3D digitisation (especially for movable cultural heritage) should take place only after the main 2D digital documentation and other basic tasks related to documentation, identification and protection of assets.

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2. SELECT WHAT TO DIGITISE AND FOR WHAT USE CASES OR USER GROUPS

- Define the rationale or purpose(s) of the 3D digitisation project.
- Focus on cultural heritage that is at risk or has high re-use value in digitised form.
- Consider the target user group(s) for whom you would digitise and how they would use such content.

- Examine the features of what you would digitise.
- Different use cases require different equipment and digitisation strategies, and different minimum quality levels.
- Involve non-digitisation departments, such as communication, education, or conservation, in co-designing and following up the digitisation project.

3D models of cultural heritage may serve different purposes that have distinct requirements. Such purposes may include detail documentation, reconstruction, reproduction, preservation, protection, research, innovation, training, education, visualisation, or online discovery and access. They translate into a wide range of use cases, including digital twins, virtual reality, augmented reality, mixed reality, timeline, research manipulations, restauration models, 3D printing, buildings and landscapes, educational applications, games, etc. Each of those main purposes requires a different level of accuracy and level of detail of the 3D model.

Defining the purpose of your 3D digitisation project and what you want to achieve from the beginning is critical. Why are you digitising? It is important to consider the rationale for a 3D digitisation project. Is the cultural heritage at risk of decay or loss? Is it especially valuable (for your organisation or others)? Is the cultural heritage regularly accessed? Is digitisation required for a specific project, for example to increase access, enable research, monitor the condition of the site, etc.?

It is also important to identify the target user group of the 3D content, and how they would use such content. Who are you digitising for? Are they professional conservators? People with responsibility for managing a historic building or archaeological site? Museum visitors? Researchers? Teachers or students? The general public? What are their needs in terms of working with 3D content?

Furthermore, another key aspect to consider is which assets would be digitised, e.g. size, volume, and whether any items require special care and attention. What are you digitising?

You may want to support conservation efforts by creating a 3D digital twin of an item for use by internal staff, or to minimise handling of a fragile asset. A different goal may be to publish the 3D content online to offer public access or to create resources for researchers or for education. Yet another intention might be to create a 3D digital twin for preservation purposes.

The answers to questions such as why you are digitising, who you are digitising for, and what you are digitising guide planning decisions for the project from the set of assets you select for digitisation to the digitisation workflow and the way access is provided. The purpose of the digitisation project determines the minimum quality requirements, and also the appropriate equipment and digitisation strategy. Purposes such as conservation or research require highly accurate representations, while educational applications may focus more on realistic visualisation. For the latter, decimated 3D models may be used to reduce the geometric complexity while preserving the appearance. There are also different standards suitable for different purposes. The final report on 3D content in Europeana published by the Europeana 3D task force also addresses the relationship between different purposes and the specific digitisation processes.

Museum collections can be extensive, and there are many cultural heritage buildings, monuments and sites, so it is unrealistic to expect high quality digitisation of everything. Among cultural heritage assets that create a higher sense of belonging, focus on cultural heritage that would serve a specific purpose in digital form, or is at risk, or has high value, including for re-use in digitised form. Where the risk of deterioration or destruction is low, make value the main criterion, e.g. societal, economic, aesthetic value, rarity. Museums, for example, could draw up a hierarchy of validity: spatial objects of high value, objects that could potentially be destroyed or damaged, etc.

When outsourcing in particular, limited funding may require selecting only a number of assets for digitisation. If funding is limited, prioritise which objects to select for digitisation. First select cultural heritage that fulfils the purpose of the project, and subsequently objects that are at risk or which have high value, including high re-use value for your intended target group.

Digitisation projects should be co-designed and followed up from the start by non-digitisation departments such as communication, education, conservation, etc.

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3. DECIDE WHETHER TO DIGITISE IN-HOUSE OR OUTSOURCE

- Evaluate your in-house 3D digitisation capabilities. What human resources, skills and equipment are available in-house? What additional resources or training would be necessary?
- Carry out a cost-benefit analysis to consider whether in-house digitisation or outsourcing offers the best value for your project.
- Consider also how easy or difficult it would be to upgrade an in-house 3D work environment, and the availability of support and learning materials for the different 3D digitisation methods.
- Persons who deal with 3D digitisation, including especially when outsourcing, must have the capacity to understand the limits of different 3D techniques as well as to analyse and judge the results.
- When outsourcing, seek technical advice from 3D experts with specific experience in the area of cultural heritage and use 3D digitisation service providers with specific experience in working with cultural heritage or in other similar or relevant areas.

Cultural institutions need to consider whether they have the necessary human resources, skills and equipment to perform 3D digitisation internally within the project timescale, or whether to outsource the project to a 3D specialist. What human resources, skills and equipment are available in-house? Is any training needed? They should also evaluate the convenience of acquiring the equipment and train operators in order to perform in-house digitisation.

Carry out a cost-benefit analysis to consider whether in-house digitisation or out-sourcing offers the best value for your project – in terms of standards and best practices, output and turnaround times, risk, quality and cost. Depending on type of heritage and intended purpose

you can get away with low/ no-budget DIY (photogrammetry), immovable heritage scanning is standard (though with photo-based texturing).

Consider the processing time for 3D-documentation. Any project whether external or internal should provide a clear list of resources needed for the entire length of the project from preparing the object to scan, to post-processing to dissemination and of course long-term storage. Resources including, time, workforce, work space, computing needs and equipment.

Consider whether any additional services or operations are needed and include them in your working schedule and budget. These may include conservator cares or transport of assets which require a team of trained.

If you decide to do 3D digitisation in-house, investigate also how easily the 3D work environment can be upgraded e.g. are the software / hardware upgradeable separately or not, and what is the meaning of upgrade costs in long run. Keep also in mind that some methods like photogrammetry are very popular and have more support and tutorial material available online.

When contracting an external service provider to digitise cultural heritage assets, it is important to specify from the beginning what the quality requirements are, which rights apply, and what data in which formats the provider has to deliver. Such providers need detailed information in order to be able to make proposals that match the purpose of the digitisation project and the category of cultural heritage involved. Such information is also essential in order to deliver all the data needed both for immediate use and for long-term preservation. Detailed specifications relating to quality and digital deliverables are also essential for properly comparing and selecting from amongst the different tenders received.

Knowledge of 3D technologies, processes and content will help whether you decide to digitise in-house capacity or to outsource. When outsourcing, expert knowledge is necessary not only to specify quality requirements, but also to verify delivered data and products. Persons who deal with 3D digitisation must have the capacity to understand the limits of different 3D techniques as well as to analyse and judge the results. It is good practice to hire 3D digitalisation specialist even if you decide to outsource the work. Furthermore, when outsourcing, it is better to use a 3D digitisation service provider with specific experience in working with cultural heritage or in other similar or relevant areas.

When considering outsourcing options, experiment also with different ways to reduce costs and create interest by engaging the general public in crowdsourcing activities. With the expectation that resources will continue to be limited in comparison to the amount of objects that should be digitised cost saving measures should, in our opinion, be investigated. Engaging the population through crowdsourcing has been shown to both increase engagement but also have the possibility to save funds and allow more objects to be digitised in 3D.

The COVID-19 crisis has highlighted the advisability of working towards the goal of digitising cultural heritage potentially in its entirety. As it is not realistic to progress in this direction based funding for outsourcing and on manual digitisation processes, there is a need, on the one hand, to develop and consolidate in-house skills, and on the other, to start thinking about automation.

The future European Competence Centre for the preservation and conservation of monuments and sites using new state-of-the-art digital technologies is expected to become a valuable source of expertise and advice.

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4. CLARIFY COPYRIGHT ASPECTS AND PLAN FOR OPEN AND BROAD ACCESS

- Identify the rights applying and the individuals and organisations holding them, and engage in discussions with them prior to starting the digitisation.
- Define the copyright that is compatible with the identified rights, and that would be most suitable for the purpose(s) for which the digitisation takes place.
- Follow and encourage adherence to the principle that what is in the public domain should remain in the public domain after digitisation.
- Integrate licensing and copyright provisions into your access and re-use agreement, and include such copyright information in the metadata.
- When outsourcing, ensure that the call and contract require that any copyright (or associated rights) , including for metadata, be transferred to the beneficiary institution or released into the public domain, and not reserved by the service provider.
- Plan from the beginning how the 3D collection will be made available to your target users.
- Provide broad public access, storing and distributing 3D models via open public platforms as well as self-hosting.
- Ensure the content is also available in open formats, in order to prevent vendor lock-in or restrictive re-use.
- Include the metadata captured as machine-readable interlinked data (Linked Open Data), in order to enhance findability.

When engaging in a 3D digitisation project, there may be certain rights in physical buildings, monuments, sites or objects to take into account. The process of 3D digitisation itself may also generate new additional rights. There may be different individuals or organisations holding such rights. Identify the rights involved and the individuals and organisations holding them, and engage in discussions with them prior to starting the digitisation.

In many countries, the law does not provide that the rights under which a cultural heritage site or object falls are transferred by default to the corresponding digitised replica. When outsourcing, it is important to make sure that any copyright needed for the planned use, immediate or future including long-term preservation, is not reserved by the service provider. ensure that the call and contract requires that any copyrights (or associated rights) are transferred to the institution or released into the public domain. This smooths the path for re-use outside of the original thought of scope. Negotiate and clearly describe rights situation of all the assets of digitisation, to ensure reuse.

Make sure that the copyright is clear. Does your organisation own the asset to be digitised or do you need to get permission from the owners? If you are outsourcing, who will own the

copyright of the captured and processed data? Have you agreed a licence that permits use and re-use of the content? Ensure that future re-use is not artificially limited, e.g. by unclear or restrictive licensing.

Encourage adherence to the principle that what is in the public domain should remain in the public domain as captured in a digital representation. This principle is described in the Europeana Public Domain Charter. It is also in the same spirit as Article 14 of the EU Copyright Directive. Even for works that are in-copyright, creating a digital representation for preservation purposes, 3D or otherwise, should not require of a collections-holding institution to have the explicit permission of the copyright holder. This is in line with Article 6 of the EU Copyright Directive.

Identify the purpose for which the digitisation is carried out, and the copyright that would be most suitable to that purpose. Ensure the chosen copyright does not needlessly limit future re-use in not yet envisioned ways. If unsure, err on the side of more freedom to re-use with the most open license possible as a standard. Open licenses make it easier to have the work stored by multiple parties, aiding in long-term preservation. This is in line with initiatives such as LOCKSS.

Integrate licensing and copyright provisions into your agreement from the start of a digitisation project, to define clear rules of access and re-use of the 3D content at any step in the digitisation process. Provide such copyright information also as part of the metadata. Use standardised, machine readable rights statements that permit reuse for commercial and non-commercial purposes, such as the Creative Commons licences (PDM, CC0, CC BY or CC BY-SA). Europeana has built up a strong copyright community and provides extensive resources and advice relating to copyright and licensing, including ready-to-use rights statements.

It is important to plan how the 3D collection will be made accessible to your target users from the beginning. Consider how users will access the content – online, in gallery, via high performance computers, via a hosting or online service, or via streaming. There are various ways of providing access, and such ways and means depend on whether your target users are internal or external, using the content on-site or online.

When they are easy to find, view and share, 3D models extend the reach of cultural heritage and enhance its influence and value. Making 3D models available publicly may be by means of service platforms and/or self-hosting. Consider public access, storing and distributing 3D models via open public platforms as well as self-hosting. In order to enable the aggregation of data at the European level, follow the FAIR principles.

Make sure that the content is available in formats that support the access you wish to provide. You may need more than one format – for example a format for 3D printing, another for online visualisation and a third for archiving. Ensure the content is (also) available in open formats to prevent vendor lock-in or restrictive re-use. There are many examples of valuable content being lost as providers go out of business or fail to keep their formats, and the tools needed to read them, up to date. Ensuring that the content is also being available through open formats helps to limit the risk.

Most often, local public links to 3D content (for example, on museums' web sites) perform poorly versus well know, supervised, optimised, constantly updated worldwide hosting platforms or Europeana. Small institutions should consider having long-term agreements with such platforms if they cannot ensure high-quality local web services.

Providing metadata to Europeana, Europe's digital platform for cultural heritage, also facilitates discovery of and online access to such content from throughout Europe and beyond. Metadata captured as machine-readable interlinked data (Linked Open Data) is very important in order to enhance findability.

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5. DETERMINE THE MINIMUM QUALITY NEEDED, BUT AIM FOR THE HIGHEST AFFORDABLE

- Quality in 3D digitisation of cultural heritage is not only about capture accuracy and resolution, but also about other key aspects such as historical accuracy, range of data and metadata generated and collected, and fitness for purpose.
- Investigate how high the capture accuracy and resolution could be, what the costs are (in time and money), and the equipment, software and skills needed.
- Determine what the minimum quality necessary is for the target users and the way they use the content, and whether the project budget and timescale permit capturing at a higher level of accuracy.
- Aim for the highest 3D capture quality for the largest number of assets that the budget and time available allow.
- What is high model quality today may become just standard in the near future, and high-accuracy and high-resolution raw data may be useful in the future to generate new, better 3D models.
- Collect, generate and include rich metadata and annotations throughout the workflow (during digitisation, processing, visualising).
- When outsourcing, specify from the beginning what the quality requirements are, which rights apply, and what data in which formats the external provider has to deliver.
- Keep in mind that, regardless of how high the quality of digitisation, a 3D model is not a 100% exact copy of the original subject.

Quality is an essential aspect in the context of 3D digitisation of tangible cultural heritage, and it is a significant challenge because tangible cultural heritage is diverse and the resulting 3D models are complex. There are many parameters involved at the different stages of the 3D digitisation process and they vary depending on the type of tangible cultural heritage, and on the equipment and methodology used. The different possible purposes or uses for the resulting 3D material also determine different combinations and levels of those parameters in order to achieve the minimum level of quality that fits the purpose. Furthermore, there are different instruments, formats, workflows and software solutions in use, without a sufficient degree of standardisation.

3D models have to be useful also as work models, and that requires high quality. 3D digitisation projects should pay special attention to criteria that define quality, such as texture

and colour management and dimensional accuracy, in order to produce reliable and re-usable digitised resources.

The accuracy of the shape (high-resolution or a high polygon count) is one technical measure, but there are also other technical attributes such as colour and texture. High quality is not only defined by resolution and accuracy, but also by the degree of how well a 3D model approximates the real object with all the features recorded, which is the basis for e.g. photorealistic 3D rendering or physical reproduction. These features include how faithful geometrical features were captured and reconstructed and how close colours captured come to a given colour reference.

Geometry and colours, however, are not all there is to a faithful reproduction, as they do not capture the dynamic behaviour of the object surface in reaction to varying illumination or when observed from different angles. Tangible heritage consists of a wide variety of different physical materials, that each have their own dynamics in this respect, such as reflectance at different intensities and distributions, angle-dependent colour changes and even translucency. Optical material behaviour acquisition tries to capture this aspect which goes way beyond geometry and texture information only. To reach highest quality and thus highest realism, capturing optical material behaviour needs to be considered whenever possible.

Equipment and strategy of digitisation also affect quality. The instruments used for capture and the algorithms involved in the processing determine the accuracy of the resulting 3D data set and model. The processing should not add any artificial visual elements or effects to the model, or at least any such transformation should be well documented and able to be separated from the original, like a different layer.

For large areas, a multiscale digitisation approach may be more suitable. It involves using medium resolution when scanning a landscape, and higher resolution when scanning a point of interest. A very high resolution on the whole area may be irrelevant. This is all the more important as scanning a large area can lead to huge data sets that become very difficult to manage, store and search in the longer run. Good data capture policies are important in order to mitigate such risk. It is possible to combine different resolutions (medium and high) in the same 3D model during the data processing stage. Nevertheless, this method usually requires a quality post-processing software and the resulting model is not always ‘watchable’.

Nevertheless, regardless of how high the quality of 3D models is, they do not replace the original objects, buildings etc. The model generated by 3D software will not be a 100% exact copy of the original subject. The model is generated from a large volume of photos or laser data, etc., and the 3D post-processing is more or less imperfect, depending on several things including the quality and number of the images, how accurate the laser data is, software settings, etc.

Museum collections can be extensive, and there are also many cultural heritage buildings, monuments and sites, so it is unrealistic to expect digitisation of everything at the highest quality possible. High-accuracy and high-resolution raw data can be used to generate 3D models for different audiences and functions. However, there is a need for balance between time, cost and the resolution and accuracy with which data is captured. The instruments needed for very high-resolution capture are expensive and the resulting datasets may take longer to process.

Considering the needs of the target user groups, and how they are likely to use the 3D content, enables informed choices. Minimum quality requirements should reflect the purpose of the digitisation project. Certain purposes, such as preservation and reconstruction, require high-

quality geometrically correct 3D models. For visualisation or VR and AR applications, optimised decimated 3D models are more suitable. Typically, high resolution models are decimated to reduce geometric complexity while preserving the characteristic features and their appearance. The quality of post-processing also has to match the required purpose.

Investigate how high the accuracy and resolution could be, what the costs are (in time and money) and the equipment, software and skills needed, and then consider the minimum level of accuracy needed for the project, and whether the project budget and timescale permits capturing at a higher level of accuracy.

Define minimum quality levels for the measurement data that will be good enough to cover your needs. Sometimes, for example, different data quality may be necessary for documenting a whole object, and much more detailed data for a small fragment just to capture some processes or tool traces. Measurements and specially data post-processing are very time consuming, so the minimum quality requirements need to make the whole process more effective and cheaper.

Nevertheless, the highest quality today may become just standard in the near future, and what is good enough now may become modest or even insufficient. In that event, high-accuracy and high-resolution raw data may be useful in the future to generate new, better 3D models that take advantage of advances in digital technology and connectivity. For that reason, it is important to aim for the highest quality affordable and perhaps limit the number of assets covered as permitted by the budget and time available. In other words, consider capturing fewer targets at a higher accuracy and resolution.

The data captured through digitisation, for example by means of photogrammetry or laser scanning, is useless without technical, administrative and provenance metadata to allow for reproducibility and traceability of the artefact. It is very important to make it easy to verify also which part of data comes from the capture process and which parts of the model have been modelled.

We digitise cultural heritage because it has historical value. Therefore, the historical information about an object or site is as important as the technical data from the digitisation process (settings, calibration data, raw data, information about the data acquisition equipment and environmental factors) and the final 3D model data such as geometry and textures of the artefact. Historical accuracy (or the research that underpins a reconstruction) is absolutely necessary in cultural heritage projects.

Comprehensive and adequate metadata, enriched with state of the art multilingual glossaries, improves discovery of models in content management systems (CMS) or digital asset management systems (DAM) and/or search engines, including in particular via Europeana. Metadata are the main key for conservation, access, use, reuse, rights management, understanding of the model and of the object digitised. Providing comprehensive and adequate metadata also enables re-use and supports archiving. Metadata should not be subject to copyright.

3D models without metadata are useful for videogames and within storytelling projects, or for virtual reconstructions, e.g. of archaeological contexts. Application of the London Charter for the Computer-based Visualization of Cultural Heritage would guarantee that models are historically accurate and refer to the scientific knowledge underlying them, with a clear distinction between reconstructive propositions based on facts and propositions of fantasy.

3D models with separate metadata are currently quite widespread, and they suffer from the separation between 3D and metadata. Metadata can be anchored to the model in a way that is not resilient to post-processing and subsequent interventions on the 3D model. Also, different 3D models will present different information granularity, which can be problematic in case of comparison or aggregation.

3D models with embedded metadata (BIM) are a more effective solution, but difficult to achieve as they still require massive manual intervention. Although the "scan to BIM" problem is unsolved yet, it is possible that rather soon it will be solved by the market, as broad professional areas (such as engineering) are addressing it beyond the cultural heritage domain. The same can be wished for the application of artificial intelligence for this purpose, which is not very advanced yet.

To be complete, metadata for a 3D object has to include also information about the cultural heritage asset, about the digital data produced and about the digitisation project itself. The latter is often referred to as paradata. Asset metadata includes information such as title, type, description, rights, location, geometry, textures, and materials. The information about the asset should also describe its cultural and historical value, and include geographic and temporal information as well.

Web or digital resource metadata includes all the technical information associated with the 3D cultural heritage objects or site such as acquisition technique, system and software specifications, reconstruction quality and formats of the 3D model. For 3D models published online also keywords are useful as they increase discoverability.

Project metadata, or paradata, includes information such as the purpose of digitisation, conditions relating to data collection and processing, equipment and methods used, the process of digitisation, and the actors involved.

Some metadata may be captured by the equipment being used in digitisation and processing. Such metadata should be captured throughout the workflow, rather than at the end of the project when time and funding may have run out. A capture/acquisition process establishing a stable and robust link between metadata and models would be of paramount importance and should be identified. However, not all relevant information can be collected with digital tools. Some metadata requires research, for example the historical or cultural value of the object. Other metadata may involve lab tests, for example materials data.

Rich metadata supports discovery, access, and understanding of the model and of the cultural heritage asset represented and of what could be done with it. Metadata should be adapted depending on the use of 3D model in order to minimise manipulation. Persistent identifiers for 3D content ensure findability of such content over time. In parallel with keeping a record of the metadata and paradata, it is also important to display and distribute the most significant metadata properties, with the dissemination of 3D models.

Labelling 3D models for their use in the framework of pattern recognition, machine learning and other artificial intelligence research approaches should also be considered. Uses and users are no longer just human: a digitisation campaign designed today must take into account the availability of metadata and digital objects for pattern recognition, machine learning and other forms of artificial intelligence based research. Besides metadata, models should be equipped with annotations (labelling) making them usable in big data and artificial intelligence contexts. The use of AI in the area of cultural heritage is currently, in fact, slowed down by the lack of adequate datasets.

Data interoperability is crucial. 3D models and metadata should therefore adopt metadata standards for cultural heritage consolidated internationally, or at European level, in order to guarantee the interoperability of the data collected. The final report on 3D content in Europeana published by the Europeana 3D task force reviews and discusses metadata schemas for cultural heritage 3D data sets and models, and makes some recommendations in that respect. The metadata schema used should be suitable for cultural heritage and for the particular type of digitised content involved. Any extensions applied to an existing metadata scheme should be clearly documented. It is recommended to store metadata in XML/RDF format, and make it machine-readable and linked (Linked Open Data).

Metadata should be organised to enable the inclusion, also at a later stage, of all information needed to use the model in order to study the digitised cultural object, its conservation and restoration, and in order to communicate it to the public. A feedback loop available for suggested improvements and corrections from re-users of the materials (what is sometimes referred to as roundtripping) would be valuable. By involving the community in the work with e.g. metadata or with the models themselves, valuable content will be created and should be possible to (re-)use by the 3D digitisation projects themselves.

CMS and DAM as metadata management systems are viable solutions at the moment, but possibly not for the longer term. It is hard to envisage that they could provide robust solutions for massive 3D metadata management, while semantic systems for organising metadata and cloud systems (such as those proposed by EOSC) emerge.

When outsourcing, it is essential to specify the purpose, standards, best practices and quality outcomes expected from the work in the call for tender. It is important to specify from the outset what the quality requirements are and what is to be delivered. That should be done by including measures of the quality required and the digital deliverables expected. Digital deliverables should include both 3D models for different immediate uses and archive files for long-term preservation. Clearly determined parameters of the data to be delivered also makes it possible to check their quality and verify whether they meet the requirements. Furthermore, not adding any artificial visual elements or effects to the model during processing should be a contract requirement, or at least any such transformation should be well documented and able to be separated from the original, like a different layer.

Quality specifications and expectations in calls to tender should be as clear and understandable as possible, such as what kind of corrections or editing is needed for the 3D models, or whether there is a need or hope for physically based rendering. Providing references to examples of other similar objects digitised in 3D would also be important. Indicate also what formats a service provider should deliver, e.g. preservation formats (open and proprietary), and which layers: point clouds as well as final assets and rendered scene. Intermediary files like meshes are of minor importance because they can be generated based on point clouds with different software. Archive files should ideally also be delivered in open format (based on the assumption that open formats will turn out to be sustainable in the long run).

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6. IDENTIFY THE DIFFERENT VERSIONS AND FORMATS NEEDED FOR THE DIFFERENT USE CASES TARGETED

- Purposes such as preservation and reconstruction require high-quality

geometrically correct 3D models, while for visualisation or VR and AR applications, optimised decimated 3D models are more suitable.

- Use the raw data to produce a master high-resolution 3D model, which would serve as the basis for decimation and conversion into different formats to serve different purposes.
- Make the content available in multiple formats, of which at least one should be an open format.
- Follow standards and best practices, and choose open and/or commonly used formats for 3D models, such as glTF, X3D, STL, OBJ, DAE, PLY, WRL, DICOM or IFC.
- Choose a viewer/platform for delivery that works on a range of devices and which can also be supported in Europeana.

The 3D raw data resulting from the digitisation process requires further processing to generate 3D models and other 3D content for diverse uses. Digitisation may serve different purposes, which can be documentation, reconstruction, preservation, research, education, visualisation, or online discovery and access. The models and content for each purpose may include high-resolution offline models, online models, interactives, 3D printable models, augmented and virtual reality models, publications, images, videos, and panoramas.

Post-processing is required after data capture to transform raw datasets into 3D models. This involves a sequence of steps to process and visually enhance the raw data. The same raw dataset may be used to produce 3D models at different resolutions, in formats suitable for printing, for rendering online, or for deposit in an archive. The raw data from the capture stage can be used to produce a master high-resolution 3D model, which can then be the basis for decimation and conversion into different formats to serve different purposes. The metadata and the paradata can be used for linking multiple version to the original 3D source when the capturing phase is the same. It would be useful to establish a process for providing the raw data and/or master model to re-users to allow them to create the 3D models that best fit their needs. Such practices will help spur innovation, interest and artistic works through and from the 3D digitisation.

The intended use of the model will also influence how the content is made available. A 3D model should, in principle, not be used for a single purpose, but become part of a broader digital cultural heritage ecosystem allowing to re-use and re-process digital information for further study or dissemination purposes. High-resolution 3D models intended for use in historic buildings conservation are likely to be made available offline on powerful computers with professional software. 3D models created for gallery interactives may be made available through gaming platforms on in-gallery equipment. For online access, use of viewers or service platforms that comply with standards, can be accessed via a range of devices (desktop, mobile, etc.) and can be embedded in Europeana are recommended.

Make sure you follow standards and best practices, wherever they already exist and it is possible. To maximise the long-term usefulness, accessibility and potential of your 3D content choose open and/or commonly used formats for 3D. This, together with clear

licensing, increases the potential for re-using the content for opportunities that may arise in the longer term. If needed the material should be made available with multiple formats, of which at least one should be an open format to ensure that the content is accessible to everybody and is persistent over time. Licensing should be made clear irrespective of the format, and it should allow for re-use.

Open and commonly used formats for generating 3D models from the raw capture data include examples such as glTF, X3D, STL, OBJ, DAE, PLY, WRL, DICOM or IFC. High-quality and high-resolution data can be stored in *.OBJ or *.DAE formats. Common formats for virtual and augmented reality visualisation are *.USDZ and *.glTF. For 3D printing *.STL and for web visualisation *.X3D and *.GLB are widely used. 3D models for printing can serve the purpose of reaching people with disabilities. The list is not exhaustive, since 3D models are generated for different final purposes. There are also other open and commonly used formats for specific uses such as IFC for the AEC industry, and such formats often already include more than just the shape. Where other formats are used, the format specification should be indicated or delivered with the data.

3D models of large areas can be very big files that become difficult to open, display and manipulate. To solve this issue, there are options such as streaming 3D models or using protocols that 'tile' large 3D models. Quite specific to the field of large 3D models, protocols that 'tile' large 3D models work by cutting such models into smaller pieces (tiles) that a computer can display more easily. Since the computer loads such smaller pieces in real time and seamlessly, the viewer experience will be that of exploring only one single 3D model. There are several formats for such 3D model management protocols: 3D Tiles developed by the Cesium Consortium (open format, and already has a wide community of users contributing to the development of the tool), Potree developed at Wien Technical University (also open format, but the community is smaller), and the I3s tiling system proposed by Esri (also open source).

In cases where the digitisation is outsourced and performed by an external provider, frequently only the final output of a digitisation is delivered to the customer. To allow for further re-use, raw data should be required as well with contextual information and metadata. The expectation is that when a separate provider (e.g. a company) is involved with the digitisation all the information created during the digitisation should be released.

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7. PLAN FOR LONG-TERM PRESERVATION OF ALL DATA ACQUIRED

- Making 3D content accessible online or otherwise does not equal archiving or long-term preservation, not even when doing multiple backups.
- Take into consideration long-term preservation from the beginning, including all aspects such as formats, storage, future migrations and re-use, ongoing maintenance and the corresponding long-term costs.
- Keep as much data as possible from the 3D digitisation process, depending on the storage and data management capabilities available, including the raw data.
- Select an archive that is able to accept the incoming digital data files, has the necessary storage space, and can offer a preservation service.
- Use and support as much as possible open file formats, software and hardware,

and consider archiving also the software and any other system needed to open the files.

- Log and store all metadata collected, including the paradata about the digitisation process, and all the different versions of the 3D model generated for various uses.
- Put in place a data management system that tags all data, in order to make it easy to store and research the data.

The process of digitising tangible cultural heritage in 3D starts with the acquisition of raw data, which refers to the data sets captured in the field and not yet turned into 3D models. In the case of photogrammetry, such raw data consists of photographs (in raw formats such as jpeg, tiff or dng) that are then processed using photogrammetric algorithms and software and turned into 3D models.

Making 3D content available does not equal archiving or long-term preservation, not even when doing multiple backups. The digital files that are produced require on-going management to ensure their preservation, integrity and future access. Long-term preservation should therefore be taken into consideration from the beginning of project planning, including all aspects like formats, storage, future migrations and re-use, ongoing maintenance, and long-term budget and costs. It is therefore important to have a strategy for the long-term preservation as well as a commitment to set aside the necessary resources, especially if the purpose of the project is preservation of cultural heritage assets at risk.

Clear plans are needed from the beginning on where to store, how to process, how to manage, how to find, use and reuse 3D models. Accumulation of 3D models in the absence of such plans would risk prioritising quantity over quality. Over and beyond the quantity of models, what counts is their use, reuse, findability, interoperability (the FAIR principles are key). Institutions should also include such aspects in their digitisation plans from the beginning in order to be aware of the long-term costs of such projects (backups, storage, data migration, etc.).

Write a data management plan, include the objectives, the target user group(s), all your decisions (and perhaps available choices) concerning digitisation and preservation, and follow it closely. Update it often. Audit the processes every year so that they are in line with the data management plan.

For long-term preservation, use a system or platform designed specifically for that purpose. It is not sufficient to upload models on more general-purpose distribution platforms. At the present time, few digital archives guarantee the long-term preservation of all the data that is produced in 3D digitisation projects (raw files, processed data, visualisations, animations, augmented and virtual reality). However, there are some standard file formats that are suitable (or likely to be capable of becoming suitable) for long-term preservation.

Decide where to deposit your collection for long-term preservation. Identify an archive that is able to accept the incoming digital data files, which has the storage space and can offer a preservation service. Discuss appropriate file formats and the metadata required for deposit with the archive and include the findings in your digitisation plans.

All data from the digitisation process is valuable. It is important to keep as much data as possible depending on the storage and data management capabilities available, including raw data (groundtruth data) such as photographs for photogrammetry or point clouds. That also requires planning for appropriate storage and archiving capacities that ensure safe preservation with multiple backup copies. Repositories for raw data, which are automatically backed up, would be particularly suitable.

Systematically keep the raw data and not just the 3D models, because technological advances and fast-progressing algorithms will make it possible to generate better models, and faster connectivity will allow larger models to be accessed online. For example, it is possible to use the same data set of raw data to generate a much better 3D model in 2020 compared to 2015, simply because algorithms improve a lot in five years. Also log and store all metadata collected, including the paradata about the digitisation process. It is necessary to save not only a final 3D model but also all measurement data, major data post-processing steps and description of the workflow. Put in place a data management system that tags all data, in order to make it easy to store and research the data.

Nevertheless, the need for as much data as possible (technical information, paradata) may be to a certain extent problematic when using an external commercial provider for producing 3D models. Some of them may consider this kind of information a trade secret.

Comprehensive archive files can be very large. The raw data for only one 3D asset may be 200 gigabyte or more. Consider storage options for the files created and plan for enough space and safe storage and preservation. Investigate questions such as what data storage options are best for that. For example, FLASH-type storage is not a good option for keeping files longer than 5-10 years. How many copies of the same DATA should you make and keep? What are the cloud computing options? Examine closely aspects such as safety, economies, access, etc. These questions are very important to consider. The CEF eArchiving building block provides standard specifications and sample software for long-term digital preservation, as well as support.

In some cases, the raw data may require some kind of continuous processing for keeping them usable. For instance, raw proprietary data may require a maintenance process, and for this reason you should choose an open format whenever possible. Sometimes raw proprietary data from some laser scanners cannot be opened anymore due to new software releases, and for this reason you should consider also archiving the software and any other system needed to open the file. The conversion may be possible only using a step-by-step procedure (version 1 to 2, 2 to 3, etc.), but big jumps from one version to another (from version 1 to 10) should be avoided, due to the risk of file corruption. This is what has happened with some 3D databases after 15 years of storage.

3D-digitisation is a rather new area and strategic work to develop open formats will solve a lot of issues and challenges and prevent new ones to occur in the future (e.g. when the commercial formats can no longer be opened because of bankruptcies etc.). One recommendation is to use as much as possible open file formats, software and also hardware. In addition, when necessary, actively support the development of open formats.

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8. USE THE RIGHT EQUIPMENT, METHODS AND WORKFLOWS

- The equipment and methods used have to match the category of cultural heritage involved and the quality needed for the purpose of the digitised assets.
- The size and characteristics of the target, the intended uses, the logistical aspects, the budget available, the timing and the environmental conditions all have an influence on the choice of equipment and methods.
- Carefully evaluate equipment outputs. What may be suitable for movable tangible assets (e.g. museum objects) may not be sufficient for immovable cultural heritage (e.g. buildings, monuments or sites).
- Photogrammetry is suitable for materials such as stone, wood, concrete, textile, plastic, or metal (matte surface), but not for shiny, transparent or highly glossy objects, nor for objects with loose/movable parts.
- For complex objects, both the work performed on site and the data processing last longer, and the work schedule should consider those.
- The use of drones, for 3D digitisation of buildings, monuments or sites, often requires a drone pilot license and specific authorisations.

There is no one-size-fits-all method for 3D digitisation. The equipment, methods and workflows that are used vary according to the type of cultural heritage (objects, monuments, buildings, sites) being digitised, the project's purpose, environment and other factors. For example, if your project is to capture a 3D model of a collection of Egyptian mummies using X-ray, you will use very specific equipment. Another project might involve creating a virtual reconstruction of a historic building for an education audience. The methods, techniques and processes in your workflow will differ from one to another.

Active methods such as laser scanning or structured light and passive methods such as photogrammetry use different equipment that produces different outputs. The methods and equipment for scanning also vary with the material to be scanned. Different surfaces require different scanning techniques. While some are suitable for photogrammetry, others are more suitable for scanning with LIDAR. There are also photogrammetry techniques for objects with loose, movable parts (with some limitations), and also techniques for shiny or glossy objects.

It is not only a matter of outputs, but also of data capturing processes. For instance, working with buildings and monuments often requires the involvement of several disciplines both for bringing together different measurements from different data sources (i.e. topography for merge LIDAR and SfM from drones) in a reliable way and for achieving holistic documentation. Certain objects and materials, e.g. glass, jewellery, and textiles, still present significant challenges for 3D digitisation. Photogrammetry is suitable for materials such as stone, wood, concrete, textile, plastic, metal (matte surface), but not for shiny, transparent or highly glossy objects. It is also not suitable for objects with loose/movable parts.

A number of factors have an influence on the choice of equipment and methods, including the size and characteristics of the target, the intended uses, the logistical aspects, the budget available, the timing and the environmental conditions. There are significant differences especially between the instruments, methods and outputs for buildings, monuments and sites

and those for museum objects and other similar artefacts. The budget available, timing and environmental conditions can also affect choices of equipment and methods. Human resources, in addition to the technological aspects, will also have to match the purpose and needs of the project.

If you are scanning an archaeological monument at a remote location, it may be impractical to return, which makes it important to capture as much detail as possible whatever the weather conditions on the day. Environmental conditions may also affect the final quality of a 3D model as the environmental errors, noise and poor lightning may decrease the model's quality. However, since usually the timing and budget are limited, the outdoor works should be planned considering weather forecast, and in the event of unfavourable weather the schedule should include time for office work.

The degree of geometrical and other types of complexity of cultural heritage assets influences the volume of work involved in the 3D digitisation process. The amount of work needed to digitise an asset is proportional to its level of geometrical and structural complexity. In case of complex objects both works performed on site and data processing last longer, which should be included in the work schedule.

Highly detailed museum objects may take several times longer to digitise, even if they are very small, compared to larger objects or sites with shapes and features that are more basic. Tangible cultural heritage with a low degree of complexity has few and very simple features. At the other end, tangible cultural heritage with a very high degree of complexity is very detailed and has a large number of complicated features that require considerably more effort to capture. In the case of buildings, monuments and sites, the degree of complexity may be very high also because of a very complex structure.

Depending on the objects' features such as their size, material, structure and texture, different measuring methods would provide best results while others would fail. The choice of a proper documentation method should consider the asset's characteristics, the features of each measuring method and desired accuracy and level of detail of the resulting 3D product.

Nevertheless, the integration of data acquired by different measuring techniques has proved to provide good results, exploiting advantages of each of applied methods and allowing to supplement the results obtained with one technique with data acquired by another. It is a particularly common approach in case of the integration of range-based techniques like terrestrial laser scanning, providing high accuracy of shape reconstruction, and photogrammetry supplying the 3D model with texture.

The outputs should be carefully evaluated in relation to processing procedures and expected results, since what may be suitable for museum objects may not be sufficient for buildings, monuments or sites. The equipment and methods used have to match the category of cultural heritage involved and the quality needed for the purpose of the digitised assets.

The use of drones is subject to regulations, e.g. it is often compulsory to hold a drone pilot license when using a drone for professional purposes, and requires specific authorisations, especially when flying above a town and people, and near restricted areas, e.g. airports.

For the 3D digitisation of museum objects, there is ongoing work to develop also automated systems.

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9. PROTECT THE ASSETS BOTH DURING AND AFTER DIGITISATION

- Regard physical conservational aspects as part of risk management during digitisation.
- Carry out a preliminary study or analysis to determine the potential impact/damage of the technique used.
- Specify from the beginning of the digitisation project who would handle the cultural heritage assets, and who may come close to them.
- Make sure that any person handling the cultural heritage assets or operating any moving 3D digitisation equipment is competent to do that.
- Have professional conservators oversee the handling of objects, and involve them from the planning stage.
- Ensure that appropriate insurance coverage is in place.
- After digitisation in 3D, avoid as much as possible direct handling of the assets in question, using instead the digital twins created.

Digitising cultural heritage may involve direct handling of cultural heritage assets or the use of equipment that moves in the proximity of such assets or outside and inside cultural heritage buildings, monuments or sites. There are, therefore, certain risks of damage in the course of the digitisation process, and it is essential to address any such risks, because the protection of the cultural heritage involved is paramount. 3D digitisation projects should consider conservational aspects as part of risk management.

The digitisation of cultural heritage should be planned taking into account first all the conservation aspects and second all the resources. It is necessary to make preliminary studies to determine the impact/damage of the technique used in the cultural heritage. It is important to consider the pros and cons of a digitisation project from that point of view.

It is advisable that the person handling cultural heritage assets is qualified to do so, has received an appropriate training or has some past experience in this regard. Where necessary, it is essential to plan to train the operators involved. The person responsible for digitising may not be the same as person handling the cultural heritage assets. Therefore, you should specify from the beginning of digitisation who is handling the cultural heritage assets, and who is allowed to come close to them.

Continuous attention should be given to movement of the equipment around the cultural heritage site or object. Make sure that any person handling moving equipment is competent to use them. Digitising using a drone or other moving equipment, for example, could be risky if the person is unfamiliar with it.

The handling of objects should be supervised by professional conservators from the planning stage.

Given the paramount importance of ensuring the safety of cultural heritage assets. The recommendation is to make high quality capture/measurements, in order not to have to repeat the process again shortly after. That would create again a possibly unsafe situation for an object.

After digitisation in 3D, direct handling of assets should be limited as much as possible. Research and other activities should take place as much as possible using the digital twin. Nevertheless, there are countless possible reasons for study and research on cultural objects and sites that may also emerge after digitisation, and for which access to the original would be essential.

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10. INVEST IN KNOWLEDGE OF 3D TECHNOLOGIES, PROCESSES AND CONTENT

- Using 3D technologies to document tangible cultural heritage is gradually becoming more commonplace, and knowledge of such technologies and processes is becoming increasingly more valuable.
- Knowledge of 3D technologies, processes and content is valuable regardless of whether you digitise in-house or outsource.
- Acquire at least basic understanding about 3D, including technical requirements.
- When engaging directly in 3D digitisation, begin with a limited scope and a limited number of assets to acquire knowledge.
- Outsourcing of 3D digitisation, too, requires an understanding of the technologies, processes and content involved.
- Training courses on 3D for cultural heritage or on 3D technologies more generally are also available online via the major e-learning and other platforms.
- If you produce learning material and/or documentation on different aspects of 3D digitisation, make that content available under fully open licences that permit re-use for commercial and non-commercial purposes.

Using 3D technologies to document buildings, monuments and sites or museum collections is gradually becoming more commonplace. It is one of the topics of high interest in the area of cultural heritage, and knowledge of such technologies and processes is becoming increasingly more valuable.

Knowledge of 3D technologies, processes and content will help whether you decide to digitise in-house or to outsource. When outsourcing, such knowledge is necessary, for example, to define quality requirements in a call for procurement and then to assess the quality of the material provided by the contractor and decide whether the work will be accepted.

It is important to acquire at least basic understanding about 3D, including technical requirements. It can be quite demanding, as technology evolves and gets better, but outsourcing, e.g. through public procurement, cannot be done properly without such

understanding. It is strongly encouraged to make digital skills, including in the area of 3D digitisation, part of the standard profile for curators and cultural heritage professionals.

Furthermore, 3D digitisation of cultural heritage cannot be delegated exclusively to technical experts, nor could it be expected that the funding needed to outsource 3D digitisation of the widespread, rich and diverse cultural heritage of Europe will become fully available. In order to achieve a meaningful amount of quality 3D models of cultural heritage objects, in-house skills for the creation of 3D models should be built. Cultural heritage professionals should have the necessary knowledge and skills in order to guarantee a quality design and management of the digitisation project, the correct addressing of copyright aspects, accessibility of the digitisation outcome, preservation of raw data and of the 3D master, and the respect of quality standards, criteria and practices including when the digitisation is outsourced.

The first step in building up 3D-related knowledge should be the auditing of in-house 3D digitisation capabilities, if applicable. That would enable an institution to determine the current level of 3D-related knowledge in-house and to plan what additional training may be needed. When engaging directly in 3D digitisation, begin with a limited scope and a limited number of assets to acquire knowledge.

Training courses on 3D for cultural heritage or on 3D technologies more generally are also available online via the major e-learning platforms. If you also produce learning material and/or documentation on different aspects of 3D digitisation the content should be made available under fully open licences that permit reuse for commercial and non-commercial purposes (PDM, CC0, CC BY, CC BY-SA). A huge amount of time, effort and money can be saved if the material does not have to be recreated over and over again. By allowing reuse and improvements of the material the quality will increase over time as well, similar to how e.g. Wikipedia has become better and better over the years when more people help to improve the content.

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