European Commission

Study on quality in 3D digitisation of tangible cultural heritage: mapping parameters, formats, standards, benchmarks, methodologies, and guidelines

Executive Summary

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STUDY ON QUALITY IN 3D DIGITISATION OF TANGIBLE CULTURAL HERITAGE

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Introduction

This study was commissioned by the Commission to help advance 3D digitisation across Europe and thereby to support the objectives of the Recommendation on a common European data space for cultural heritage (C(2021) 7953 final), adopted on 10 November 2021. The Recommendation encourages Member States to set up digital strategies for cultural heritage, which sets clear digitisation and digital preservation goals aiming at higher quality through the use of advanced technologies, notably 3D.

The aim of the study is to map the parameters, formats, standards, benchmarks, methodologies and guidelines relating to 3D digitisation of tangible cultural heritage. The overall objective is to further the quality of 3D digitisation projects by enabling cultural heritage professionals, institutions, content-developers, stakeholders and academics to define and produce high-quality digitisation standards for tangible cultural heritage.

This unique study identifies key parameters of the digitisation process, estimates the relative complexity and how it is linked to technology, its impact on quality and its various factors. It also identifies standards and formats used for 3D digitisation, including data types, data formats and metadata schemas for 3D structures. Finally, the study forecasts the potential impacts of future technological advances on 3D digitisation.

1. The process of digitising movable and immovable tangible cultural heritage – key concepts

According to UNESCO[1], Tangible Cultural Heritage (CH) encompasses movable, immovable and underwater heritage. The digital recording of CH is an essential step in understanding and conserving the values of the memory of the past, creating an exact digital record for the future, providing a means to educate, skill, and communicate the knowledge and value of the tangible objects to the society. The digital representation of CH objects, structures, and environments is essential for practical analysis, conservation and interpretation. Selecting the ideal technology and workflow for the 3D digitisation of tangible CH objects is a complicated, challenging procedure that requires careful consideration of the following parameters.

Accuracy and precision

Accuracy refers to how close a measurement is to the true or correct value, whereas ***precision*** is how close the repeated measurements are to each other. Measurements can be both accurate and precise, accurate but not precise, precise but not accurate, or neither. A reliable survey instrument is consistent; a valid one is accurate.There is no internationally accepted framework or methodology for specifying the quality of detail and accuracy in CH digitisation.

Planning the process of digitisation

The recording of tangible CH requires a thorough understanding of the stakeholder requirements, the necessary technical specifications, the existing environmental conditions, and the intended use of the final 3D model. Selection of the optimal human resources and digitisation technology are usually related to the technical specifications, size, complexity, material, texture, location, accessibility, intellectual property rights and accuracy required. For large surface areas, such as monument sites or architectural mapping, a combination of regular aerial and topographic surveys, laser scanning and photogrammetric techniques is often used. In addition to the cost of hardware and associated software, a considerable investment in knowledgeable staff and time dedicated to specialised training has to be taken into account. Therefore, any project planning should accurately address and coherently develop a documentation dataset, while keeping in mind project constraints including environmental and safety conditions, available equipment, skilled human resources, budget, and timescale.

[1] UNESCO: https://bit.ly/3oEEdRB

Active and passive recording

The 3D digitisation of tangible CH is an inherently complex multi-stage process. Documentation methods involving radiating systems may be grouped in ***penetrating*** (like X-Rays in medicine or cosmic rays for pyramids) and ***non-penetrating*** (like electromagnetic energy covering the visible and InfraRed spectrum). However, for 3D applications possible little penetrations inside the material are usually neglected, and this is the reason why light sources for 3D never go beyond near InfraRed. Within non-penetrating devices, a further distinction has to be done between ***active*** and ***passive*** systems; active methods use directs radiant energy to mark a point in space, whereas passive methods record the reflected radiation from a surface.

Indoor and uncontrolled acquisition

Indoor image acquisition is more often used for objects or artefacts in museums or collections (which are not allowed to be moved), typically of small or medium size, and presents several challenges. The size, weight, special illumination conditions, materials, properties of the artefacts, and their interior structure directly influence the documentation complexity. ***Uncontrolled*** acquisition is typically used for outdoor scenes or any other environment where the conditions (shadows, weather, etc.) are not under complete control. Large scale objects such as buildings, excavations, or archaeological sites with high accuracy demands (mm-cm) are classified in this category.

Determining complexity

Complexity is a critical consideration when planning a geometric documentation project. It concerns the geometric, surface/texture, material composition, and scale/application variants. In addition, a key dimension of complexity also resides in the stakeholder requirements, which may include the location, condition, set-up of the data acquisition project, experience of the multidisciplinary operators on site, and the fusion of multiple datasets from different devices and their users/specialists (equipment and data pre-processing) into one archive that can be visualised in an easily accessible and searchable way.

An online survey aiming at establishing perceptions of the 3D digitisation community (944 responses received from 420 survey respondents) identified the following parameters as the top three factors for increasing complexity: a) Surface conditions; b) Site access; and c) Quality of scanned data.

Moreover, interviews during our work with 49 key stakeholders and skilled professionals in 3D digitisation showed that among the factors most frequently mentioned were the importance of the stakeholders' requirements for 3D digital documentation frameworks, object conditions before/during the recording process, location and environmental conditions during digitisation, and the levels of expertise of the people involved.

The challenge is to manage all related activities that run simultaneously during the data acquisition phase to produce high-quality results without losing information. Optimal digitisation technologies are usually related to the desired technical specifications, size, condition, material, texture, location, accessibility, and required accuracy. These considerations are incorporated into the ***operational schema*** developed during the study.

How is complexity connected to technology?

Some data capture technologies and recording methods are more suitable for specific applications than others (such as computer tomography). Selection of the data acquisition technology are usually related to the desired stakeholder requirements, technical specifications, size, complexity, material, texture, accessibility, and required accuracy. The report describes mainstream technologies used for the 3D documentation of CH tangible assets in terms of the degree of complexity.

Impact of complexity on quality

The complexity of 3D digitisation of CH can be defined after the stakeholder requirements are determined, the project specifications are set, the object's location and environmental conditions are known, and the object is defined. The study's online survey analysed the perception of complexity that experts have concerning the use of technologies. In their opinion, complexity is related to the degree and kind of information they want to obtain, issues with software and budget, challenges that the surface of a specific object presents, and location of a monument.

Any definition of object complexity should have the following characteristics:

- It refers to both 3D data capture and data processing point cloud/modelling,

- It is calculated objectively,
- It is estimated before the data acquisition phase,
- It connects quality, technology, and the purpose of use,
- It provides alerts and limits to recording and processing phases, and
- It offers a meaningful tool for planning both the data acquisition and the 3D modelling process.

Any definition of the complexity in 3D digitisation of CH assets should consider the following parameters:

- The stakeholder's requirements, including total budget and time duration,
- The definition of the object and its detailed description,
- The location of the object and the environmental conditions during the time of the documentation,
- Multidisciplinary key expertise and is expected to be available for the documentation,
- The data acquisition equipment are calibrated and software are updated and available, and
- The knowledge for high tech hardware and software to be used and are updated and available for the pre-processing of the scanned 2D (images) and 3D data (3D point clouds).

2. Exemplification of complexity

During the study, the set of parameters determining levels of complexity and related more broadly to quality were considered in the context of 43 cases (25 Immovable and 18 Movable). A catalogue of data acquisition technologies and their output formats, as well as was developed. Annex 1 of the report provides outline descriptions of each case. Other contextual taxonomies have been developed for movable and immovable heritage. When building a taxonomy of complexity for movable heritage, we must consider each unique element (object-specific). An essential requirement for *the* ***holistic digitisation*** of an asset refers to collecting data regarding these factors and accurately representing them.

3. Parameters that determine quality

Quality is a fundamental component of the 3D digitisation in CH, and it is an essential challenge since tangible CH hand- or natural-made structures are remarkably different. Quality may comprise different parameters such as the degree of detail, the geometric accuracy of the 2D and 3D shape, the spectral, scale and texture, material properties and chemical composition, and structural health monitoring status. These parameters can be combined in the following categories: a) Geometry; b) Image; c) Material; and d) Structural Health Monitoring.

Quality parameters refer to different stages of the 3D digitisation process and vary depending on the type of tangible CH and the equipment and methodology used. The possible purposes or uses of the resulting 3D material also determine different combinations and levels of those parameters to identify the minimum level of quality that fits the definition.

From the study's survey responses, the top three parameters of quality categorised as the most important by respondents to ensure quality in the digitisation process were: a) surface conditions, b) quality of images, and c) environmental conditions.

The possible uses for the resulting 3D material also determine different combinations and levels of those parameters to achieve the minimum level of quality that fits the definition. It is also essential to distinguish the differences between data accuracy (as an acceptable margin of error), precision and resolution regarding the geometry.

4. Standards and benchmarks

One conclusion of the study's 49 interviews with key professionals is that there are no standards for planning, organising, setting up and implementing a 3D data acquisition project. Some experts mentioned the need to distinguish between the standards available for the management, administration of projects, safety, health and accessing the object/site for the personnel, the movement of the objects and the standards available for the data processing and representation.

The report analyses most usually employed formats and provides a full discussion of terrestrial laser scanning/3D modelling and photogrammetry/digital photography. It elaborates on the distinctions to be made between proprietary and open-format data limitations (minimum or maximum), and on judging data correctness in the absence of international protocols for data quality assurance. An important observation is that formats evolve as users and developers identify and incorporate new functionalities.

5. Identification of gaps, additional formats, standards, benchmarks, methodologies, and guidelines

There are no guidelines on ways and minimum amounts of data to be collected or the quality to be achieved during data acquisition, which entirely depends on stakeholder requirements. There appears to be little common understanding among the international multidisciplinary teams regarding what 2D/3D digital data acquisition standards means, as well as the obsolescence when new software does not provide backwards compatibility with older file formats.

When defining a project, it is crucial to understand the stakeholder requirements about the various production file formats to avoid inconsistent deliverables and inoperable proprietary data sets. There are hundreds of different file formats, noting that terrestrial laser scanners, for example, produce raw data in a variety of formats. Proprietary formats, such as TIFF or JPG, are seen as robust; however, these formats will ultimately be susceptible to upgrade issues and obsolescence. Furthermore, open-source formats can be seen as being neutral, non-reliant on business models for their development; however, they can also be seen as vulnerable to the susceptibilities of the communities that support them.

At the novice level, or for those with limited expertise, different and more basic forms of guidance may be required to promote skills that enable widespread 3D digitisation in Europe. Some of the key questions have been around the conceptual framework needed to address the use cases for digital dioramas, including by adding depth to the current 2D images, and by embedding one or more canvases within a 3D scene. However, with growing user and institutional demands, technical developments, and examples of advanced research collection and integration of virtual resources (e.g. Sketchfab, Smithsonian3D, 3DHOP, Potree, ScanTheWorld, Clara.io, morphosource.org, exhibit.so, hubs.mozilla.com, sayduck.com, Europeana.eu, etc.), there is a pressing and urgent need for a technical specification to ensure interoperability and longer term sustainability.

6. Uncertainty

Recognising the challenges and lack of consensus on the expression of uncertainty in measurement, different organisations worldwide have collaborated with the Comité International des Poids et Mesures to develop a more workable definition. Uncertainty concerning the complexity and quality in data acquisition is discussed in the report in the context of the expression of quality in 3D digitisation.

7. Forecasted impact of future technological advances

Expected advancements in 2D/3D data acquisition software combined with artificial intelligence algorithms in different devices will make 3D digitisation easier, faster, more accurate, and more informative. The automatic compilation of different data types from various devices and manufacturers, the extraction and recognition of geometrical features, materials and environmental issues will create new challenges and impose greater demands. Development in this area will likely require new competences, specialised expertise and training. New standards, regulations and internationally accepted methodologies for data acquisition will be required.

Moreover, automatic compression and data transfer through 5G, 6G and strong Internet connections with many gigabytes of bandwidth from the field to the cloud will soon be in place to enhance archiving, real time global use and long-term availability and preservation. Guidelines for the CH domain will be needed on future formats for data, metadata and paradata, ensuring interoperability and data longevity. For analytics, blockchain, cloud and mobile computing, ontologies, Internet of Things aerial and terrestrial LiDAR, and machine learning are just a few technologies that have transformed the construction industry and will undoubtedly impact the CH sector very soon. The increased interest in A/V/MX Reality, unmanned aerial vehicles, Artificial Intelligence/Machine Learning, cloud and mobile computing will enable these new systems to play an indispensable role in the management, documentation, modelling, conservation, interpretation and protection of CH. Consequently, the development of these systems will have a direct impact on the CH industry (i.e. Virtual Museum, Virtual Sites, Smart Cities, 3D digital libraries, fabrication and eArchiving). The report explores the potential of these technologies in more detail alongside that of open data, Heritage Building Information Modelling (HBIM), Holistic BIM (HHBIM) and digital twins.

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