Adapting the technology and technical parameters of measurement in three dimensions in the digitisation of cultural heritage artefacts to enable the use of resulting data

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Introduction

With the recent advancements in 3D measurement technology, digitisation has become a key issue, with major impacts on the way of documenting and preserving cultural heritage. The use of advanced three-dimensional measurement technologies enables precise mapping of historical objects, opens up new possibilities in the field of restoration, studies and digital showcases. One of the key benefits of three-dimensional measurement technology is its ability to create metrological, spatial documentation of cultural heritage artefacts. Accurate 3D scanning and modelling can be used to achieve a faithful representation of the details, textures and shapes of objects, which enables them to be stored and shared in a digital form to the extent that was never possible before. As such, digitisation became a way of preserving and archiving manifestations of heritage in order to enable safeguarding them from destruction, degradation and loss.[1]

Unfortunately, achieving the appropriately high quality and accuracy of the resulting documentation is fraught with many challenges, as it requires using technology solutions offering the highest resolutions, and this often entails significant financial outlays and time-consuming processes. At the same time, many museums and cultural institutions tasked with safeguarding artefacts are unable to carry out these complex projects, which can be a major roadblock on the way to comprehensive digitisation of heritage objects. In search for funding, museums turn to external sponsors (including the European Union), who often require them to participate in competitive tenders. In spite of access to these opportunities, many institutions are unable to carry out projects that require them to contribute a part of the costs.

Additionally, not all objects can be measured accurately using commonly available technologies. Complex shapes, highly reflective surfaces, objects made of transparent or translucent materials, as well as artefacts with very delicate structures that make them difficult to move, as well as large objects can prevent accurate data collection and 3D modelling. As a result, some information about the object may be omitted or gathered incorrectly, which can impact the quality and completeness of the digital documentation created.

The selection of appropriate measurement technologies with digitisation of cultural heritage objects in mind is an important matter for discussion.

1 Developing digital documentation does not stop the progression of the potential deterioration process of a historic artefact and thus does not absolve the responsible institutions from the responsibility to preserve their historic substance. Nevertheless, comprehensive three-dimensional documentation can have a significant impact on any conservation works, especially when restorations are required (editor's note).

If the goal is to enable as many cultural institutions as possible to digitise their collections, a balance needs to be struck between the measurement quality, efficiency and maturity of the given technology, as well as the labour-intensity and cost of a given project. Another crucial aspect concerns the development of accessible standards concerning project documentation that cover the issue of validating the quality of the obtained data.

The first section of the paper will cover the importance of properly planning the measurement process for each individual artefact. The second section features suggestions concerning the use of measurement technologies, illustrated with examples of material culture artefacts.

Stages of the measurement process

In order to obtain the right result of a three-dimensional measurement, the measurement process must be planned accordingly. The process comprises three stages:

Stage I

The starting point for every measurement process should be establishing the precise objective of the process. Whether the results of the measurements are to be used for advanced scientific research, for studying the object with conservation or restoration in mind, for educational showcases or online presentations, has a significant impact on the budget required to carry out the digitisation process. The choice of the appropriate measurement technology is directly linked to this objective.

The suggested list of objectives of taking 3D measurements of cultural heritage artefacts:

1. Perpetual comprehensive documentation of the geometry of the object

This objective entails taking three-dimensional measurements with the highest possible level of precision achievable at the current state of technological development in order to collect data concerning even the most subtle surface features. This kind of data is extremely useful for studies, as well as planning and carrying out conservation work and ensuring that the artefact is preserved in the best possible condition for future generations.

2. Perpetual documentation of a fragment of the artefact

In some cases, there is a need to document only a specific part of an artefact, for example due to its unique features or in connection with the related research. Given this situation, a decision can be made to use the most advanced measurement technology to enable in-depth analyses and studies based on the data obtained; however, the high cost and time-consuming character of such measurements means that they can be limited only to the selected parts of the object's surface. The remaining parts of the artefact are documented using lower-quality 3D documentation or 2D photographic documentation.

3. Documentation for the purposes of developing a physical model using 3D printing techniques for educational purposes

In many cases, the artefact is digitised in order to obtain a 3D model that can then be used to create a 3D printed copy. These situations rarely require documenting the finest details of the object, as reproducing them during the printing process is going to be impossible.[2] In this case, the measurements can be carried out at a lower resolution, with focus mainly on the shape and general features of the object, in order to make the resulting model sufficient for 3D printing.

4. Documentation for presentation purposes

In a situation where the cultural institution needs a presentable 3D model, precise measurements of the geometry of the artefact are not as necessary due to the fact that the 3D model will be simplified to a significant extent, while any metrological imperfections of the geometry will be masked by a photorealistic texture applied to its surface.

If the objective is to carry out in-depth scientific research or study the object as part of its conservation process, the institution will need to employ high-precision measurement technologies with high spatial resolution in order to map out even the finest details. Carrying out such a process usually requires significant financial outlays to either purchase or rent specialised equipment and employ trained staff.

If the goal is to enable presenting the object for educational purposes, obtaining an attractive and clear model of the artefact supersedes precision and accuracy. In this case, lower-resolution technologies will prove sufficient, enabling digitisation at a lower cost thanks to the lower volume of spatial data recorded and processed.

In the case of online showcases, the most important aspects include ensuring accessibility for the end users and interactive character of the model. The choice of the right measurement technology is just as important as ensuring the possibility of creating virtual representations of the object during the digitisation process to enable development of its story and make it available in relevant outlets.

The choice of measurement technology thus depends on the objective of the digitisation process of a cultural heritage artefact. When planning the budget, all the costs need to be taken into account, including the cost of technology (the cost of the equipment and ensuring proper conditions required for taking the measurement), the cost of taking the measurement and processing the obtained data, as well as the cost of training the staff who would use the data.

2 The quality of the resulting 3D model should be aligned with the level of geometry reproduction in the 3D printing technique chosen for the given project, e.g. Computerised Numerical Control, or CNC (editor's note).

Stage II

The second stage – the most crucial stage of the entire process – is an in-depth analysis of the artefact, since its characteristics, size and number of details will determine the choice of the measurement technology. The analysis should be carried out with due precision in order to choose the right technology and determine the scope of required work.

Depending on the material characteristics of the object, such as texture, transparency, porosity and reflectivity, it may be necessary to use not one, but several measurement technologies to successfully complete the digitisation process.

It is also important to consider the size and number of details of the object. Objects characterised by a large number of details, such as sculptures or ornaments, will require a high-resolution measurement technology in order to obtain an accurate representation of every detail. Larger objects, on the other hand, such as buildings and architectural features, can usually be measured with lower-resolution technologies due to the fact that taking a measurement of such a large area (which in some cases may exceed hundreds of square metres) would result in large volumes of spatial data, even at a much lower sampling rate. Large objects, such as buildings or rooms, can be measured using Time of Flight laser scanning, while fine sculptural or architectural details usually require more precise measurement technology, such as structured-light scanning.

Choosing the wrong measurement technology can cause a significant increase of the cost of the process, and in the worst-case scenario it might result in the failure of the process due to its excessive technical complexity. If the choice of the measurement technology is not properly aligned to the characteristics of the object, it can render obtaining accurate and precise data impossible, thus affecting the quality of the mapping and the usefulness of the resulting 3D data.

Before choosing the appropriate measurement technology, a comprehensive analysis of the artefact needs to be carried out, as making the right choice will enable achieving the optimal quality of measurement results in line with the relevant objectives while minimising costs and the risk of failure.

Stage III

The third stage comprises taking three-dimensional measurements in line with the assumptions and the objectives of the digitisation process. This stage requires precision and care; in many cases it also requires working with highly-qualified technical staff.

Based on the analysis of the object and the selected measurement technologies, the institution can proceed with the collection of measurement data. The most important aspects of this process include following the relevant measurement procedures and methods in order to obtain optimal results for the given method.

Carrying out three-dimensional measurements can involve a variety of techniques and tools, such as time of flight laser scanners, structured-light scanners, photogrammetric data capture devices and other specialised equipment. Calibration and proper configuration of the solutions is paramount, just like making the measurement in line with the best practices and documenting it in the final report.

During the process, the staff needs to focus on a number of aspects, including appropriate lighting conditions, ensuring stable operation of the equipment, minimising factors that may impact the measurement (such as vibration) and selecting the correct settings. The safety of the documented object and protecting it from any possible damage is also important.[3]

Performing spatial measurements with due care enables gathering precise data concerning the object. This data can then be used to create digital models, virtual tours, interactive presentations or other digital representations.

That is why ensuring the highest possible quality of measurement data at this stage is vital, as the results will be used for further digitisation processes and will form the basis of the object's use in digital environments.

Summary of objectives, technologies and measurement algorithms

To sum up the first stage of the digitisation process, the following table presents the suggested measurement technologies relevant to the stated objectives:

Objective	Suggested measurement technologies
Perpetual documentation of the artefact (documentation, 3D printing)	– high-resolution structured-light scanners – laser triangulation scanners – high-resolution photogrammetry – high-resolution handheld scanners – TLS laser scanners
Studies, 3D printing	– high-resolution structured-light scanners – laser triangulation scanners – high-resolution photogrammetry – high-resolution handheld scanners – TLS laser scanners
Perpetual documentation of a fragment of the artefact	– high-resolution structured-light scanners – laser triangulation scanners – high-resolution photogrammetry
Educational showcases, educational 3D printing, online presentations	– laser scanners – handheld scanners – photogrammetry

3 Any project involving the production of digital documentation of cultural heritage artefacts should be consulted at the planning stage with the art conservator responsible for the object in question. Some practices which may be considered normal in industrial settings may be unacceptable when it comes to cultural heritage artefacts (editor's note).

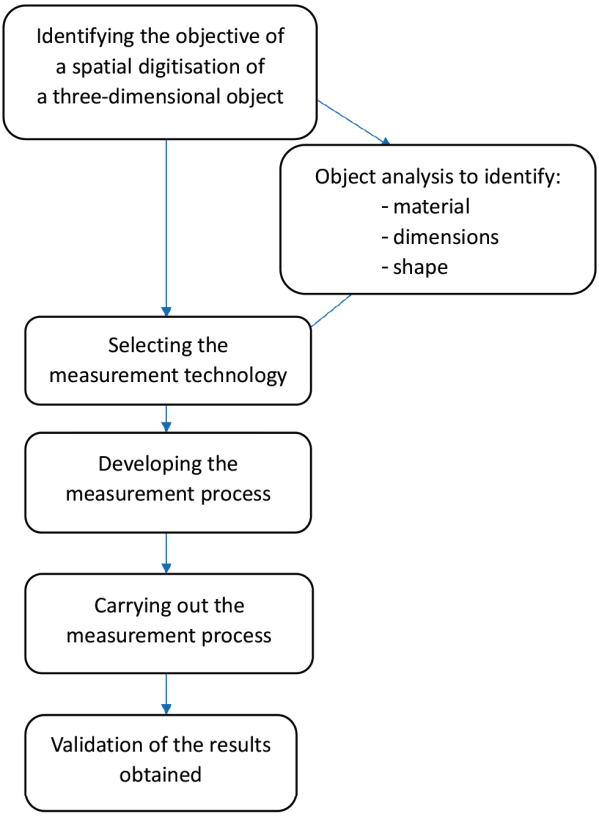
To sum up the second stage of the digitisation process, the following table lists the suggested technologies according to the physical characteristics of the object:

Object type	Parameter analysed	Suggested measurement technologies
Large-scale architectural structures, e.g. castles, churches, buildings	dimensions of the object	– TLS laser scanners – ground-based photogrammetry – aerial photogrammetry
Medium-sized architectural structures, e.g. chapels, sculpture sets	dimensions of the object	– TLS laser scanners – ground-based photogrammetry – short-range aerial photogrammetry
Large areas	dimensions of the object	– TLS laser scanners – aerial photogrammetry
Medium-sized objects, e.g. free-standing sculptures, larger sculptures (with any dimension larger than 2 metres)	dimensions of the object	– TLS laser scanners – short-range aerial photogrammetry – handheld scanners – ground-based photogrammetry
Small (moveable) objects, e.g. small-scale sculptures	dimensions of the object	– handheld scanners – photogrammetry – structured-light scanners
Highly detailed objects	surface area of the object	– structured-light scanners – handheld scanners – photogrammetry
Objects with uniform texture, rough surface	surface/material of the object	– structured-light scanners – handheld scanners – ground-based photogrammetry
Objects with uniform texture, glossy[4]	surface/material of the object	– laser triangulation scanners – structured-light scanners – handheld scanners – photogrammetry
Objects consisting of several elements made of different materials	surface/material of the object	– handheld scanners – photogrammetry – structured-light scanners – laser scanners

4 Any of the methods listed in the table can be used to make a three-dimensional measurement of a homogeneous/glossy surface; however, this requires setting up the measurement station and the optical system of the measuring device accordingly. For example, the appropriate polarisation of illuminated and reflected light needs to be added in order to reduce glare.

The measurement technologies listed in the tables recur in many cases. This is mainly because there is some overlap in the application, parameters and capabilities of the technologies. What is more, the subject has been simplified in order to present the various possibilities instead of addressing the detailed issues connected with choosing appropriate measurement technologies for a specific object. In most cases, the objective will determine the technology choices in any digitisation process; however, there are some notable exceptions to that rule.

The flowchart of the comprehensive digitisation process should look as follows:



Depending on the objective, various types of 3D documentation may be required. Additionally, it should be borne in mind that the choice of a particular scanning technique and device does not determine the quality of the obtained measurement data in itself. Most measurement methods leave the possibility of adjusting the parameters of a given set-up (in the case of structured-light scanning, for example, this involves installing different optics on the scanner and recalibrating the device to a different measurement volume).

Combining measurement technologies to optimise the digitisation process

The description of the second stage of the process mentions the need to select the appropriate measurement technology depending on the size, material and detail density. It is worth noting that in some cases, proper documentation of a specific object might require gathering measurement data using different technologies in order to optimise the digitisation process and ensure its proper quality.

This might be the case for a large historic building with numerous small bas-reliefs characterised by fine details. Depending on the objectives of the measurement, laser scanning technology can be used to document the building as a whole, while high-resolution photogrammetry coupled with structured-light or laser scanners can be used to accurately measure the bas-reliefs. The combination of these techniques enables achieving high-quality texture, while ensuring detailed geometry mapping in selected areas.

Another example concerns a sculpture made of single-colour glossy ceramic, which can be difficult to measure due to the lack of characteristic points that enable accurate reconstruction of the object's geometry. In this case, it is best to use active measurement technology, such as laser triangulation, and photogrammetry techniques to gather texture data.

There are many other cases where combining various measurement techniques may prove fruitful. This is usually the case for large or complex objects, where some elements can be measured at a lower resolution, while others require high resolution to accurately capture fine details.

Using a combination of different techniques may be necessary to obtain a complete and accurate digital representation of an object.

Accuracy and quality, a defined measurement process and the development of spatial measurement standards

According to many opinions, the resolution of the point cloud and the polygons obtained on its basis are crucial; the more points per 1 mm^2 or cm^2 of the object's surface area, the more accurate the digital representation of its geometry. However, density is not the only parameter responsible for the accuracy and quality of the spatial measurement, as any measurement made with the most accurate device or system can be distorted in a way that will make it unusable. For this reason, the resolution and technical capabilities of the device should not be the only factors determining the requirements in tender procedures and the acceptance of the completed work. Other key factors include:

– precise representation of the object to scale;
– representation of the finest details of the object (previously selected and indicated as required on the scan); this parameter may also be used to indicate the resolution of the measurement;

– the dimensions of the object at characteristic points of its geometry, allowing verification of the dimensions and its parts during the validation process;
– measurement coverage (in %), crucial when it comes to measuring architectural objects;
– validation of the measuring equipment used for each measuring process with known accurate templates.

The development of standards concerning spatial measurements in the context of digitisation of cultural heritage objects is thus crucial to enabling the selection of relevant requirements for tender procedures; otherwise, the institutions may find it difficult to develop digitisation projects and to obtain high-quality data.

The implementation of a standard concerning a comprehensive description of the measurement process will streamline the process of generating three-dimensional models and ensure the highest quality of the results.

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The study was carried out within the framework of the author's individual work.

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