The first attempt for standardisation in 3D digitisation. The EU Study on quality in 3D digitisation of tangible cultural heritage

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ABSTRACT:

This paper focuses on the exceptional results of the EU Study (Commission et al., 2022) to map the parameters, formats, standards, benchmarks and methodologies relating to the 3D digitisation of tangible cultural heritage (CH). The overall objective of our paper is to further the quality of the 3D digitisation process by enabling cultural heritage professionals, institutions, content developers, stakeholders and academics to define and produce high-quality digitisation standards and sustainable conservation models for the preservation, documentation, understanding, and accessibility of tangible cultural heritage assets. The aim is to achieve high quality results during the 2D and 3D recording process of CH tangible assets. This work identifies for the first time in this domain, key parameters of the digitisation process, estimated the relative complexity and how it is linked to technology, its impact on quality and its various factors. It also presents standards and formats used for 3D digitisation, including data types, data formats and metadata schemas for 3D structures within a holistic documentation approach. Finally, this work presents and describes all the features and parameters of the complexity and quality that influence the methodology and infrastructure to be used for high quality results regarding digital cultural heritage. These complexity and quality factors are illustrated in the form of radial charts with the corresponding relevant information at the end of the paper.

1. INTRODUCTION

The aim of this work is the process of 3D digitisation and documentation of movable and immovable tangible cultural heritage which is crucial for the protection, preservation and renovation of CH objects. Additionally, the 3D digitisation process can significantly improve the accessibility of unique cultural heritage objects for research, innovation, education and enjoyment. Digitised 3D cultural heritage tangible objects can be used in several ways such as:

- High-quality 3D scans and data can be used by archaeologists and engineers in conservation, protection and conditional /structural evaluation;
- Medium-quality data for 3D printing is widely utilised in the creative industries, education, the video game industry, and within XR applications;
- Online platforms, repositories, and infrastructures provide low- or high-resolution 3D structures to support the work of academics, archaeologists, museologists, historians, architects, engineers, transdisciplinary researchers/experts, and students;
- More generally, 3D data may be used as graphical records in national collections management systems, with the possibility of aggregators like Europeana collecting them and/or the creative industry using data for digital marketing and promotion.

Analysis, protection, interpretation, and long-term preservation of CH tangible objects, buildings, and environments all depend on their digital representation. The process of choosing the best technology and technique for the 3D digitisation of tangible, movable, and immovable CH items is challenging and needs careful thought.

The possibility of outputs in more complex formats, such as high-resolution 3D, which can be integrated into special effects workflows for the creative industry (such as in films, games, virtual exhibitions, digital cultural tourism and education, etc.), as well as for rapid prototyping by manufacturers, is something that museums, sites, and monument owners are increasingly looking into.

2. THE PROCESS OF DIGITISING TANGIBLE CULTURAL HERITAGE – KEY CONCEPTS

The digital recording of CH tangible assets 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 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 non-trivial procedure that requires careful consideration of the following parameters.

(i) Accuracy and precision of the measurements.

It is vital to make a distinction between data accuracy, precision, and resolution and decide what acceptable margins of error are in order to explain the digitisation process, particularly when working with documentation systems and the accompanying dimensions data. The heritage artefact or scenario needs to be examined more closely the more accurate the model is. **Precision** is the distance between repeated measurements, whereas **accuracy** is the measurement's adherence to the true or accurate value. Measuring results can be precise and accurate, precise but not accurate, accurate but not precise, or neither of the two. A survey instrument may be precise (returning similar values each time a measurement is conducted) but inaccurate (because the recorded values returned are not close to the actual value) or accurate (recording a value that is close to the actual value for a measured point). A valid survey instrument is accurate, and a reliable one is consistent (Bryan et al., 2020), (Historic England. (2017)), (*Historic Environment Scotland. (2018)*).

(ii) Planning the process of digitisation.

The recording of tangible CH requires a thorough understanding of the stakeholder requirements, the required technical requirements, the current environmental conditions, and the intended application of the final 3D model (Layers of Perception, 2007, n.d.), (Georgopoulos & Ioannidis, n.d.).

The best human resources and digitisation technologies are typically chosen based on the required technical parameters, including size, complexity, material, texture, location, accessibility, and accuracy. It is common practice to combine routine aerial and topographic surveys, laser scanning, and photogrammetric techniques for large surface areas, such as monument sites or architectural mapping. A large investment in knowledgeable employees and time devoted to specialised training must be considered in addition to the price of the hardware and associated software. Consequently, any project planning should specifically consider and build documentation in a cohesive manner.

(iii) Active and passive recording

The 3D digitisation of tangible CH is a multi-step, fundamentally difficult process. Radiation-related documentation techniques can be divided into penetrating (like X-rays in medical or cosmic rays for pyramids) and non-penetrating (like electromagnetic radiation that spans the visible and infrared spectrums) categories. The slight penetrations that could occur inside the material for 3D applications are typically disregarded, which is 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 recording methods. **Active recording** methods use directed radiant energy to designate a location in space, while **passive recording** methods capture the radiation reflected from a surface. Terrestrial laser scanners (TLS), structured light scanning (SLS) devices, and range cameras are examples of active sensors. Systems for passive or image-based documentation include aerial photogrammetry (cameras), terrestrial photogrammetry, and close-range photogrammetry (using satellites, aircraft, and UAVs). These technologies record both the surface texture and geometry of an object's surface (Böhler, Wolfgang, 2002), (Weng et al., 2019).

(iv) Indoor and uncontrolled acquisition

Indoor image acquisition presents several challenges due to special stakeholder permissions, illumination conditions, and the characteristics of the artefacts themselves (size, complexity, surface, colour, reflectance, material, etc.). Indoor acquisition is typically for objects or artefacts in museums or collections, such as paintings, pottery, or sculptures - typically small (up to a few centimetres) or of medium size (up to a couple of meters) - requiring "mm" accuracy. For in-studio acquisition procedures, special equipment, tripods and remote triggers are commonly adopted to achieve optimal results (Luib, 2019), (Marshall et al., 2019).

Uncontrolled acquisition is typically used for outdoor scenes or other settings where the conditions (lighting, shadows, weather, etc.) cannot be completely controlled. Larger scale items with high precision requirements (mm-cm), such as structures, excavations, or archaeological sites, are classified in this category. Various terrestrial and aerial platforms, such as different kinds of vehicles, stands, tripods, and UAVs, can be used for image capture, including portable devices.

(v) **Determining Complexity**

When organising a geometric documentation project, complexity is an important factor to take into account. It focuses on the variations related to geometry, surface/texture, material composition, and scale/application. The stakeholder requirements, which may include the location, setup, and experience of the multidisciplinary operators on site, as well as the combination of various datasets from various devices and their users/specialists (equipment and data pre-processing) into one archive that can be visualised in an easily accessible and searchable way, represent another important aspect of complexity (Figure 2). The following characteristics were selected as the top three causes for increasing complexity in an online questionnaire, which was part of the EU Study (Commission et al., 2022), aimed at gauging opinions of the 3D digitisation community (944 answers were collected from 420 survey respondents): a) Surface conditions; b) Site access; and c) Quality of scanned objects.

3. PARAMETERS THAT DETERMINE COMPLEXITY

In this work, a "process" is described as an extended series of events or actions that bring about change through several phases. It resembles an interactive model where factors like stakeholder requirements, 3D object properties (like technical know-how and equipment), and environmental parameters can interact and rearrange entities like activities, decisions, and contexts. As a result, the proposed Data Acquisition Process Management System of the EU Study offers a key infrastructure to design and manage various processes in the domain of 3D digitising tangible CH objects.

The proposed approach is summarised in Figure 1 which illustrates the relationship between complexity and quality in a logical dynamic graph for a 3D digitisation project. Figure 2 provides an overview of the parameters of complexity to be considered starting with the requirements for the 3D object by the owner/stakeholder and moving through aspects related to object description, project definition, team characteristics, environment, equipment and pre-processing to the final deliverables. Following are more specific and technical details for the complexity parameters with their corresponding radial charts.

(i) Figure 3 shows that the equipment part of the complexity graph has two broad sections: **Software and Hardware**. For the software component, one may have to select between open source, customised, commercial, or a mix of these. A significant difference in Hardware projects depends on whether they are carried out indoors or outdoors. However, the demands for processing power, bandwidth, memory, time, and cost are always based on the limitations of the matching hardware.

(ii) The requirements for digital CH **data pre-processing** might vary greatly, depending on the scalability of the data to be obtained. As a result, the demands for Data Consolidation / Registration (collection, selection, merging or integration), Cleaning (missing value imputation, noise control), Transformation (normalisation, aggregation/discretisation), and Reduction (decreasing number of variables/cases, balancing skewness), each coming with its own hardware and software implications (Figure 4).

(iii) According to the purpose of digitisation, desired level of detail, location, type, etc., time allocation and resource allocation, in general, are indirectly controlled by every complexity factor resulting from **stakeholder requests**, including the assigned time horizon, total budget availability/priority, and overall vision (Figure 5).

(iv) The digitisation process is governed by complexity factors resulting from **object attributes or specifications** (Figure 6), such as states of conditions, physical, chemical, and functional properties, as well as dimensions, classifications, transportation permissions, and any other object-specific concerns (health and safety, legal, ethical, etc.).

(v) The **Project parameter** comprises every complexity factor involved in managing and monitoring digital CH project performance (Figure 7). To efficiently share resources, experience, knowledge, and skill in the quest for collective intelligence, subject to any physical, operational, technological, or budgetary restrictions and requirements, an integrated management framework must be established.

(vi) The **Team/expert parameter** includes all complexity aspects related to personnel grouping, including HR accountability and responsibility (Figure 8). These complexity factors include team creation, communication, interaction, and cooperation. Additionally, this includes user credentials, appropriate internationally recognised certification, licenses, and distribution of equipment and infrastructure, as well as interpersonal coordination and quality assurance consequences in the field.

(vii) Included here are any **environmental conditions**, controlled or not, that may be seen to add to the complexity. This section takes into account both long-term (climate) conditions that are known to hinder the acquisition of 3D data in general, such as rain, snow, wind, frost, fog, and sunshine, and physical measurements that are crucial for reporting, such as temperature, humidity, barometric pressure, wind speed/direction, air pollution, etc. (Figure 9).

4. IMPACT OF COMPLEXITY TO QUALITY

Once the project specifications are established, the stakeholder needs identified, the location and environmental conditions of the item are understood, and the object is specified, the complexity of 3D digitisation of CH may be defined. The study's online questionnaire (Commission et al., 2022) looked at how experts perceived the complicated usage of technology to be. According to the respondents, complexity is influenced by the quantity and type of information sought, problems and financial constraints of software, difficulties posed by an object's surface, and the location of a monument.

Any definition of **object complexity** should include the following characteristics: (i) It describes the collection of 3D data as well as its processing and point cloud/modelling, (ii) It is calculated objectively, (iii) It is estimated before the data acquisition phase, connects quality, technology, and purpose of use, (iv) It provides alerts and limits to recording and processing phases, and (v) It offers a useful tool for scheduling both the data acquisition and 3D modelling processes.

The following factors should be taken into account when defining **the complexity of 3D digitisation of CH assets**: (i) the stakeholder's needs, including overall budget and time length, (ii) the location of the object and the environmental conditions at the time of documentation, (iii) The object's description in depth and definition, (iv) key knowledge from several disciplines anticipated to be available for the documentation, (v) that the data acquisition equipment is calibrated and software is updated and available, (vi) the knowledge for using high-tech hardware and software to be used and is updated and available for the pre-processing of the scan.

5. PARAMETERS THAT DETERMINE QUALITY

Quality is a fundamental component of 3D digitisation in CH and impacts 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 (Figure 10).

Quality parameters refer to different stages of the 3D digitisation process and vary depending on the type of tangible CH targeted, the equipment and the methodology used. The purpose and/or potential use of the resulting 3D material also determine combinations and levels of those parameters. Further details for the quality parameters with their corresponding graphs are as follow.

(i) All quality aspects in answer to the complexity imposed by the characteristics of the **material(s)** involved could interact with the digitisation process. Those include chemical composition, moisture, corrosion, carbonation, resistance, and porosity (Figure 11).

(ii) An important Digital Cultural Heritage (DCH) quality factor is the extent to which the digitisation process responds to different **structural changes** that imply a condition assessment that goes beyond common compositional analysis. This assessment covers states of conservation, connectivity, foundation strength/integrity and quality of the material for large-scale built objects, monuments, and sites (Figure 12).

(iii) Accuracy and precision are two computational geometry quality characteristics that frequently correspond with **2D characteristics** that may be effectively expressed on a coordinate plane. With improved capturing resolution in mind, relative measures are frequently approximated with consideration for point density requirements and associated (lack of) completeness (Figure 13).

(iv) Similar quality issues may also apply to **3D geometry**, as it frequently requires sophisticated signal processing techniques and (semi-automated) modelling methods to generate high-resolution point clouds using specialised equipment (multi-view cameras, depth sensors, TOF, etc.). Relative measurements may need computationally demanding self-calibration/registration and synchronisation techniques in situations with complex backdrops or texture, 3D moving objects, or severe occlusions (Figure 14).

(v) When it comes to DCH digitisation, realistic 3D visualisations that permit object representation in three dimensions are frequently the key to high **image quality**. Specifically, determining and modifying **textures** based on observed physical material properties like opacity, contrast, and granularity to the point at which approximations of the exterior structure match the required form accuracy and colour depth (Figure 15).

(vi) The relative size (or distance) between the image and the (radiometric) characteristics depicted on the ground is commonly used in digital CH as a measure of potential image detail. The accuracy of the measured distance as well as the spatial resolution (pixel ratio), which affects colour range and (bit) depth, determine the quality of the computed **scale** (Figure 16).

(iii) Image quality in DCH is often defined by **spectroscopic** features achieved via theoretical, experimental, and numerical techniques that strive to meet multi-objective photometric criteria (spectral regions). These include Absorbance, Transmittance, and Reflectance levels mapping to particular source, range, wavelength and frequency configurations (Figure 17).

From our study so far, the top three parameters of quality categorised as the most important by the digitisation process were: a) surface conditions, b) quality of images, and c) environmental conditions.

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6. STANDARDS AND BENCHMARKS

The formal definition of a standard is a "document, established by consensus and approved by a recognised body, which provides for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context"[1].

Project standards are set to attain the project's goals in a planned and organised way. Standards used may vary from project to project but the goals are usually similar - that is to complete the project according to and under the defined requirements, and within the set timeframe. Standards regarding planning, organising, setting up and implementing a 3D data acquisition project in the area of DCH ensure reliability, consistency, interoperability and secure a high level of quality of results and data.

The EU Study elaborates on the distinctions to be made between proprietary and open-format data limitations (minimum or maximum). A **proprietary file format** is the property of a stakeholder containing data ordered according to a specific encoding scheme. Data generated by users may need proprietary software to read their files, and may need to pay to use the software programme and be unable to read or modify the source code. An **Open-source format**, as the name suggests, is available for anyone use as a file format for storing digital data; typically it may be implemented by proprietary, payment free and open-source software, under the software license. These formats are usually considered 'neutral', and are not dependent on a commercial opportunity for their development. Furthermore, the EU Study analyses the most usually employed formats and provides a full discussion of terrestrial laser scanning/3D modelling and photogrammetry/digital photography. Existing 2D and 3D data formats – and their related metadata – were identified and analysed with a view to determining the state of the art and the most suitable formats for the complete description of 3D CH assets and flexibility in allowing the addition of new features required by multidisciplinary experts. The analysis was based on <u>universality</u> (ability to be used without conversions among several software applications), <u>interoperability</u> (ability to be imported and used without loss of information), and <u>flexibility</u> for extensions (ability to add more features) to fit the needs of the multidisciplinary CH community involved in 3D digitisation. According to the study, the same 2D/3D format should be used among project components to avoid translations that might lead to changed model representations (and the loss of information) and the ability to perform registration from multiple 3D scans for additional processing. Additionally, the creation of 'watertight' models (i.e. without holes or undefined spaces/areas) is necessary to ensure 3D models can be printed correctly.

Moreover, the study also focuses on evaluating data correctness in the absence of international protocols for data quality assurance and in analysing those remaining gaps regarding standards in the area of CH digital documentation, archiving, presentation, and preservation. An important observation that arises from the study is that formats evolve as users and developers identify and incorporate new functionalities.

7. THE IMPACT OF TECHNOLOGICAL ADVANCES ON CULTURAL HERITAGE

The significant increase in connectivity and smartphone technology advancements (such as cameras and processors) will provide better and richer visitor experience for CH. Furthermore, the availability of the technology on a consumer device could be an enabling medium for heritage building information modelling (HBIM) and digital twin efforts in construction and heritage facility management. Digital twins constitute virtual replicas of physical components or entities and the dynamics of those entities. These twins are data-rich, 1:1 models that behave in the same way as their original counterparts (Juan and Hallot, 2019).

Cloud computing technology is already becoming a necessity as CH digitisation projects continue to grow with increasingly faster and smarter laser scanning systems, integration of photogrammetric imagery, high-resolution images, renderings, and animations. Therefore, scan data become securely shareable with administrators, clients, scholars, experts, and contractors anywhere in the world, while at the same time point data from CH sites are held on secure servers.

A future technological advance could be the direct integration of licensed HBIM infrastructures and other required 3D software packages in a common Cloud space, within the European Data Space for Culture, giving the EU CH stakeholders the possibility to work with their objects and collections from anywhere on smart devices.

Moreover, automatic (AI) integration-based systems are expected to support the design, optimisation, and implementation of the digitisation process by optimising steps and by supporting the automatic enrichment of para/metadata and helping to increase the quality of 3D data sets.

Blockchain technologies are already showing promise regarding digital heritage preservation and public access synergies. Considering issues of authenticity and provenance in digital heritage, especially for objects or artefacts of significant cultural value, security protocols for digital information/data protection are very important. Blockchain technologies can efficiently support controlled stewardship, ownership, and exhibition management. To ensure sustainable operation, it is critical that policymakers and users understand blockchain system architectures and fully recognise their transformative potential, to increase collective awareness, engagement and participation.

8. CONCLUSIONS

The study pays special attention to the fact that 3D digitisation of tangible CH is an exceptionally complicated process, with numerous factors limiting the eventual quality of 3D CH assets.

The study demonstrates that complexity and quality are fundamental considerations in determining the necessary effort for a 3D digitisation project to achieve the required value of the output and lead to new possibilities for the standardisation and long-term 3D para-/meta- / data preservation. It identifies several parameters that are significant in setting both the production effort and standard of output.

The digital revolution over the past 30 years has had a profound impact on CH fundamentally transforming the sector. Digital technologies now constitute the primary means of collecting, preserving, and disseminating CH, and play an indispensable role in the management, conservation, protection and reproduction of CH. These technologies have had (and will continue to have) a direct impact on the CH sector and society as a whole; it is therefore vital that digitisation processes are understood as much as the act of digitisation itself.

[1] https://www.iso.org/sites/ConsumersStandards/1_standards.html

9. FIGURES

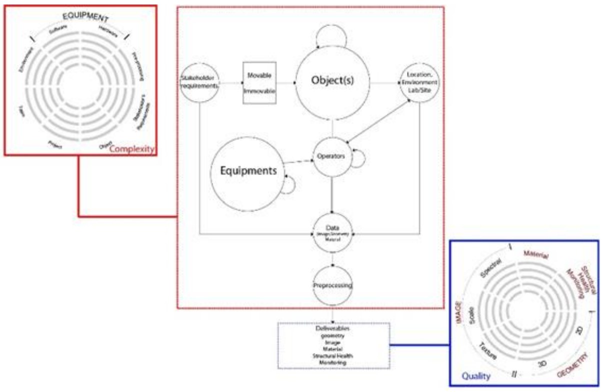

Figure 1 Overview diagram illustrating the relation of complexity to quality

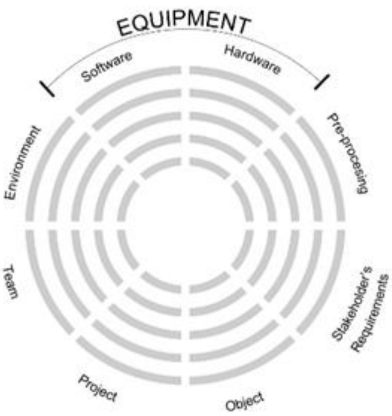

Figure 2. The Radial-Pie-Chart for the estimation of complexity for a 2D & 3D digitalisation

Figure 3. Layers of the Software and Hardware Equipment complexity parameter

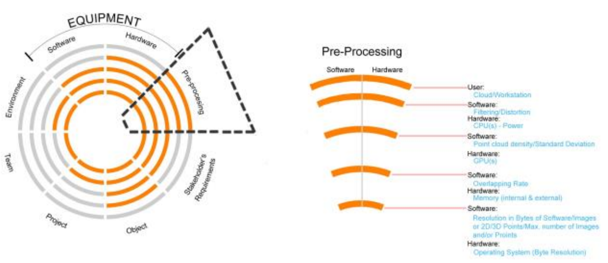

Figure 4. Layers of the Pre-processing complexity parameter

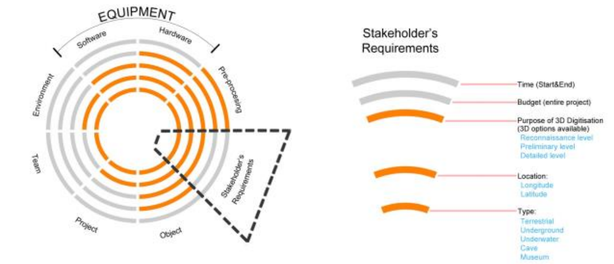

Figure 5. Layers of the Stakeholder's Requirements complexity parameter

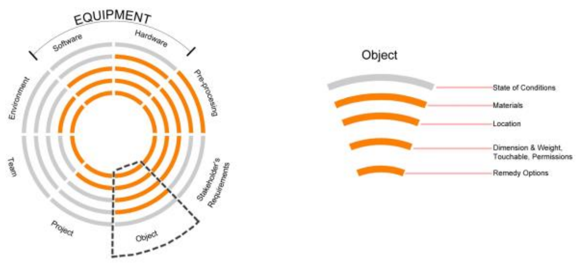

Figure 6. Layers of the Object complexity parameter

Figure 7. Layers of the project complexity parameter

Figure 8. Layers of the Team complexity parameter

Figure 9. Layers of the Environment complexity parameter

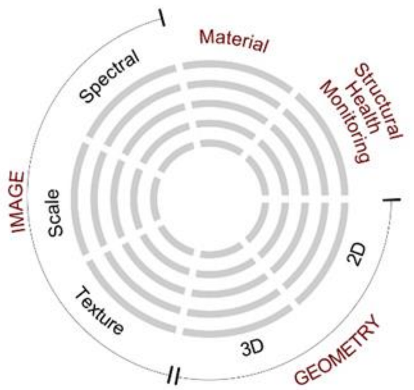

Figure 10. The Radial Pie Chart for the estimation of quality in the digital documentation of 3D objects

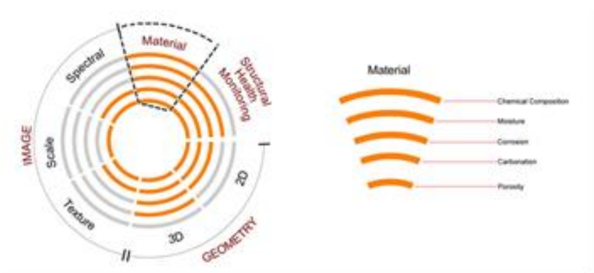

Figure 11. The Radial Pie Chart showing the layers of the Material quality parameter

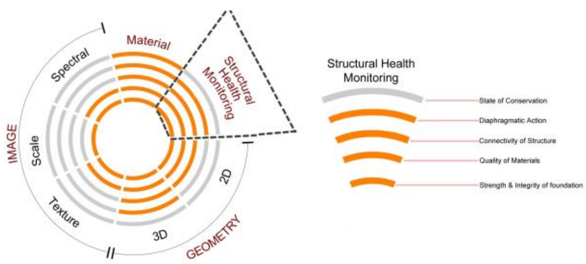

Figure 12. The Radial Pie Chart showing the layers of the Structural Health Monitoring (Changes) parameter

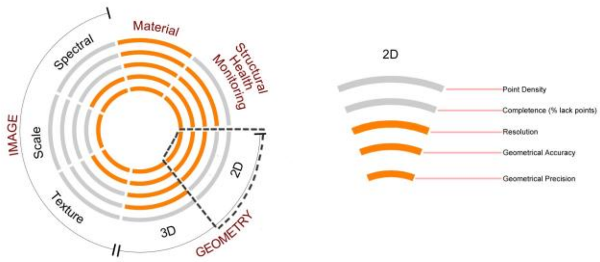

Figure 13. The Radial Pie Chart showing the layers of the 2D geometry quality parameter

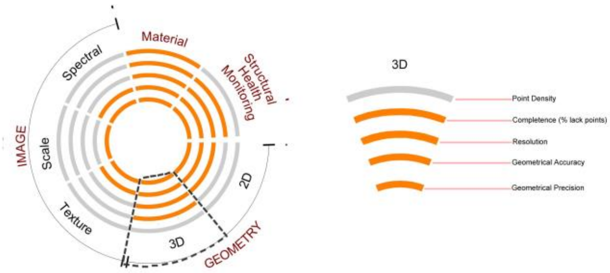

Figure 14. The Radial Pie Chart showing the layers of the 3D geometry quality parameter

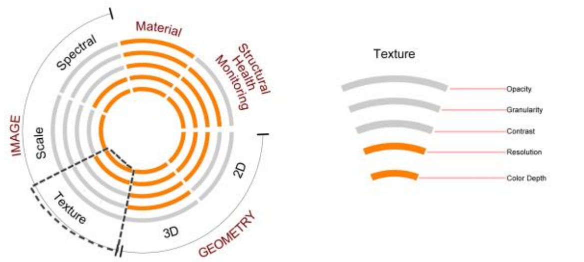

Figure 15. The Radial Pie Chart showing the layers of the Texture image quality parameter

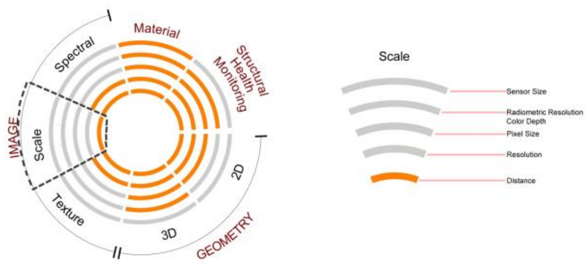

Figure 16. The Radial Pie Chart showing the layers of the Scale image quality parameter

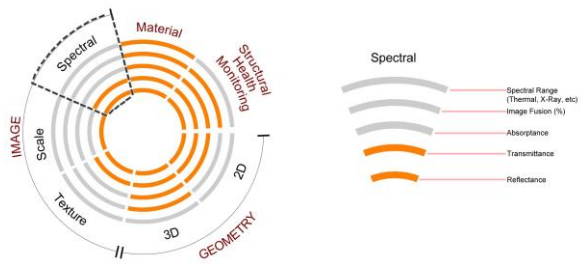

Figure 17. The Radial Pie Chart showing the layers of the Spectral image quality parameter

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