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Scan4Reco

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Deliverable

D2.3. Scientific end-user and public requirements

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List of definitions & abbreviations

Abbreviation	Definition
EU	End user
EUR	End User Requirement
CH	Cultural Heritage
WP	Work Package
VM	Virtual Museum
DSS	Decision Supporting System

Executive Summary

In this deliverable the primary input to subsequent System Architecture (WP2) as well as to planning the experiments on mock-ups (WP3) and to choice of pilots is given. The document provides also the specification of the criteria against which the acceptability of the project' achievements will be evaluated after they have been developed.

Since this is a specification of requirements from the user point of view, the contents of the documents are essentially non-technical.

The document' layout is the following: in the introduction the project aims are described and the current deliverable is positioned within the project's architectural/conceptual workflow.

The contribution of this deliverable to the other tasks of the project is also highlighted. The project context surveys similar works developed in the EC framework and highlights the Scan4Reco's novelties and improvements.

Afterwards, the end-user requirements definition process is described, with the identification of the end-user classes (curators, conservators and conservation scientists). The end-user partners (OPD, Of-ADC and UNIVR), basing on their expertise in the field of cultural heritage conservation and scientific investigation, worked together to set up a preliminary set of EURs to be refined and prioritised in the following phases of the process. Internal meetings in the premises of the OPD were then set with other professionals (conservators and archaeologists) and finally a questionnaire was distributed on-line to reach a broader group of stakeholders. In Section 4 the methodology to prepare, distribute and fill in the questionnaire is described. The next section reports on the targeted analysis of two typologies of artefacts (namely paintings and metal objects) and on the needs and questions raised by their study and their conservation. The analysis of these needs drove the identification of the questions in the questionnaire but, in an iterative process, the replies to the questionnaire were also functional to the description of specific needs through the description of the state of the art.

In the Section 6, a list of numbered and prioritised EURs is reported, with a description of the specification for each of them.

Finally, Annex I reports the replies to each questions in a graphical form and in Annex II the questionnaire form is shown.

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1. Introduction

The Scan4Reco project aims at developing a novel portable, integrated and modular solution for customized and thus cost-effective, automatic digitization and analysis of cultural heritage objects [1]. The overall project will combine multi-sensorial 3D scanning to collect multi-modal and multi-spectral data and document cultural objects. Collected data will be employed to support scholars in their work by delivering them detailed digital surrogates of cultural objects, in order to understand the heterogeneous nature and complex structures of these objects, to identify the broad and varied classes of materials that compose them and to understand their degradation mechanisms over time.

This deliverable deals with the identification of the requirements for the system so as to meet the needs and the expectations of a target group as large as possible (Task 2.4). It is crucial to the overall project layout since it summarizes the End User Requirements of the Scan4Reco system, which have been derived by augmenting the expertise present in the Scan4Reco consortium with feedback gathered from expert end users. The outcomes presented herein, along with the specification of the sensing probes and modalities of the system developed in Task 2.1, is the starting point for the definition of the system architecture. This aim can be reached by a strict co-operation between end-users (OPD, Of-ADC, UNIVR) and technical partners in Scan4Reco, which should lead to the preliminary identification of possible use cases and analysis scenarios and to assess trade-off between CH needs and technical feasibility. Finally, a further aim of Task 2.4 is to formalize in this deliverable a list of end-user and public requirements.

The outreach of this deliverable includes WP3 and WP7. The former deals with materials selection, samples preparation, application of artificial ageing and treatments, measurements of samples and ageing factors extraction and modeling and the input coming from this deliverable must be taken into account in order to select material and samples related to actual conservation issues. WP7 is on Scan4Reco validation in a realistic environment through trials on genuine artworks and the choice of case studies will be made according to the needs and the problems highlighted by end-users in this document.

2. Project context

A relevant need in the CH domain is to have efficient documentation for cultural assets both for conservation and curatorial uses and for display purposes. This requirement is more and more fulfilled by 3D digital acquisition and visualization tools, as the aims and achievements of other EU projects show (for example 3D – COFORM project [2] or GRAVITATE project [3]).

Experts involved in artworks care, management and conservation also need to characterize the objects in terms of material composition, technique of realization and state of preservation. All this information provides a full knowledge of the history of the art object and an insight on the on-going processes of deterioration. The combination of several punctual (analytical) and imaging, portable, non-invasive diagnostic techniques is the state of the art approach, developed for example in CHARISMA project[4] and now continued in IPERION_CH [5].

The ambition and the novelty of Scan4Reco is to bring together the accurate 3D reconstruction and the fusion of the data acquired with a multi-modal and multi-scanning platform in order to provide smart and predictively accurate assistance to conservators and to facilitate interactive analysis and exhibition of objects of cultural heritage. A further target of the Scan4Reco project is providing a holistic insight in the past and future state of the cultural asset, targeting to restoration processes based on pragmatic evidence and not just

on inferred contextual and historical metadata as derived from other datasets or (non-)experts opinions. The end users of Scan4Reco system are therefore domain experts, which need to have access to high-quality and verifiable data.

3. End-user requirements definition process

The definition of the end-user requirements has taken into account input gathered from domain experts.

While the Scan4Reco system aims to be effective in broad cultural heritage scenarios, we focused for the definition of end-user requirements on two specific target applications, painting and metal art objects. Maintaining this specific focus has facilitated the identification of specific experts and end-users and led to the definition of well-targeted requirements.

The identified end-users classes are the following:

- Curators: experts in charge of collections, belonging both to national or local institutions (art historians, archaeologists). They take care of collections, plan maintenance operations, set up the display and storage conditions, make decisions on performing restoration interventions
- Restorers/conservators: they take care of the material state of the work of art, monitor their conditions over time, deal with active and passive protection methods, apply restoration treatments such as cleaning, consolidation, protection
- Conservation scientists: they have a scientific background and apply scientific investigation techniques for art history, conservation and monitoring purposes. They span from chemists, physicists, computer scientists, engineers, material scientists and so on.

All these stakeholders will be using the Scan4Reco system on artworks for different purposes: curators may be more interested in visualization aspects as well as in the knowledge of the material aspects and of their changes over time, while restorers may be more focused on the aid they can receive from the Decision Supporting System and the knowledge of the behaviour of a certain material upon exposing it in certain environmental conditions. Conservation scientists, as being the ones who run investigation and measurements and interpret data in an inter-operative process with curators and restorers, will be maintaining the system after its deployment.

In order to define the requirements, we applied the following process:

- Focus groups of end-user partners:

  End –user partners of Scan4Reco are the following:

  OPD: The Opificio delle Pietre Dure is the end-user of choice for the Scan4Reco outcomes. It's a world-renowned conservation Institute that includes several professionals and competencies. Its mission is to perform pilot restoration interventions, to draw guidelines and recommendations, to take part to advisory boards on conservation projects, to test new materials and procedures, to train conservators. The OPD uses a multidisciplinary approach to conservation, combining the expertise of their staff, which includes conservators, art historians and conservation scientists. The OPD has research partnership with national and international institutions, such as the Italian CNR and the Getty Foundation Centre. Its experienced staff working in the Scientific Laboratory, in the Department for Painting Conservation and in the Departments of Metal and Jewellery Conservation

provided a valuable insight into the state of the art and the experts' actual needs on material characterization, digital representation of art objects, painting and metal analysis, prediction of material behaviour. The OPD works in contact with the main museums and collection at national level, such as the Uffizi Gallery in Florence, the Opera del Duomo Museum in Florence, the Museo Civico Medievale in Bologna, and the Cathedral in Siena. Some restoration works are carried on in-situ, when the objects are not movable or their moving is not advisable, sometimes else, as in the case of easel paintings and jewellery items or little bronze statues, the work is carried out in the OPD premises. The OPD laboratories are very well equipped to provide conservators/restorers any kind of support, from documentation to scientific investigation.

Of-ADC: The Ormylia Art Diagnosis Centre performs interdisciplinary research in a wide range of applications in the field of analytical investigation, documentation and preservation of artworks and monuments of cultural heritage with particular expertise on Byzantine Iconography. It operates through permanent cooperation with University departments, multilateral international co-operation with other research infrastructures and institutions and participation in National and EC research projects. Specialised instrumentation, high technology facilities and appropriate know-how allow for the application of complementary techniques and methodologies to the characterization of a wide range of materials and the integrated study of diverse typologies of artworks offering high-level services to the Cultural Heritage Community. Among returning users of ORMYLIA infrastructure are Scientists, Conservators, Museums, Cultural Heritage Ephorates, Churches and individuals. The Centre provides educational work in cooperation with National and European higher educational institutes, aiming at the promotion of the science of conservation, the establishment of scientifically documented conservation methodologies, according to modern technological capabilities and implementation criteria, and the promotion of interdisciplinary research for the documentation and protection of works and monuments of Cultural Heritage.

UNIVR: the group at University of Verona dealing with CH analysis is focused on the implementation and use of optical techniques for non-destructive diagnostics and on (near- and mid-) Infrared spectroscopy studies. They performed several diagnostic projects in collaboration with museums and local heritage trustees (in Italy, Soprintendenza), such as the frescoes by Leonardo Da Vinci in the Sala delle Assi (Milan), the frescoes by Paolo Veronese in the San Sebastiano church in Venice. UNIVR has an active partnership with the Soprintendenza of Venice and of Verona that is focused on innovation and technology transfer in diagnostics. Working in contact with scholars and experts in the field, the group gained knowledge on their needs and expectations about scientific investigation.

Experts belonging to these institutions and involved in the Scan4reco project worked to the definition of a first set of EURs based on project focus and on their expertise in the field.

- Focused meetings and discussions with involved experts: internal meetings were organized at the OPD to discuss the first set of EURs identified in the first step. Potential users were identified in the OPD staff: in the Scientific Laboratory (conservation scientists with background in chemistry and physics and experienced in diagnostics and materials for art), in the Departments of Conservation of Metal and Jewellery and Conservation of Easel Paintings (restorers with a broad experience in the evaluation of the state of preservation of an art object, in the choice and application of various treatments, in the evaluation of the treatment performances) and in the Department of Microclimates Sensing. Also an archaeologist experienced in collection care was interviewed. Users were interviewed to define the needs and

requirements of each target user group. Emphasis has been put on the identification of special needs of each user, in particular of experts in the field of metallic objects and paintings, so that the final system will adapt to the needs and abilities of each individual.

Goal is to refine EURs and to have expert information on specific subjects.

- Semi-guided questionnaires to the target user groups and analysis of their responses: a semi-guided questionnaire was prepared in order to refine the list of EURs and to rank them. The questions were prepared according to the preliminary list of EURs. After the agreement on the questionnaire content by all the Scan4Reco partners, it was distributed among contacts of the project partners, mainly people involved in technical/scientific aspects of conservation: metal and painting conservators of SMEs and public institutions and conservation scientists working in private companies and in public institutions. Curators were also contacted since they are responsible of collection care.

Goal is to gather feedback on EURs, to refine the list of the requirements and to define their relative importance

As far as the **general public requirements** is concerned, relevant inputs came by people in charge of museums and collections. The respondents to the EUR questionnaire belonging to the curators group were further contacted and some of them were interviewed on the options of visualization enhancement offered by the project. Their point of view is particularly interesting since they gather the public feedback on how the art items are displayed and on how relative information is provided. Traditional object labels in museums are called “tombstones” since they offer the public a very static approach to the art objects and can be insufficient and/or misleading. Under this respect, curators welcome every innovation that can help the visualization of all the surfaces of objects and of all the material and stratigraphic information. The access to a Virtual Museum via web could fill the gap between the traditional way of display and the need of innovative ways to facilitate the experience of the object. The VM cannot replace the physical visit to the museum or collection but can support it and make it a broader experience.

4. Methodology of questionnaire preparation and distribution

This section describes the methodology followed to prepare and distribute the questionnaire on the EURs. The criteria to fill it in are also reported here.

The questions have different aims. Some of them mean to show the state of the art of decision making on restoration and investigation of art objects. Other questions are aimed at ranking the needs for innovative tools provided by Scan4reco already identified by the experts. A particular care was given to keep the time for replying short (no more than 15 minutes).

The questionnaire was distributed on-line among the partners’ contacts (see Section 3) with a short e-mail message to explain the purpose of the survey. For certain questions, people were allowed to choice no more than 3 options.

The feedback was quite good. About half of the persons contacted filled in the questionnaire. Curators were the less prone to reply since they are usually overwhelmed with questionnaires and surveys.

Respondents skipped some questions since they were out of the professional field and/or because the difficulty to interpret the question text. In general, the questions where a text is required were the least answered.

5. Targeted analyses

The Scan4Reco system will be initially developed for metallic works and paintings.

The expert involved in meetings and discussions focused on some aspects of these two kinds of art objects. In general, metallic objects need protection against corrosion and interaction with pollutants. The main problems in metal works conservation are related to the performances over time of the protective coating and to the changes of the surface and material features. Among the possible issues related to this typology of objects, we chose as use cases silversmith works conserved indoor and bronze sculptures conserved both indoor and outdoor. The patina and protection layers that are usually laid on top of these surfaces undergo visual, structural, and molecular changes over time and partially or totally lose their functionality. Therefore, it is important to follow and model the behaviour of these systems (metal/coating) in order to choice the most suitable protection treatment and display conditions.

Very often paintings exhibits a very complex overlapping of layers with not original layers due to ancient restorations and re-paintings superimposed to the original ones. In between the layers and on top of the surface, layers of transparent varnishes are found. One of the main problem when studying and restoring painting is to identify and reconstruct the original painting layers.

Both metallic assets and paintings have variable size, ranging from a few centimetres to meters. They – expecially metallc objects- also have different shapes, from human figures to geometrical decorations. Experts in the CH domain need to explore all or part of the objects surface and to produce 3D digital reconstruction of the whole item or of magnified areas, which are representative of some degradation processes or of certain restoration procedures applied in the past.

According to the experts opinion and the questionnaire outcomes, the main aims to perform investigation on artworks are to help establish the causes of deterioration and to address art historical questions. Providing a guide to choice the restoration treatment is also a motivation for investigation. Under these respects, the Scan4Reco system can provide a valuable aid for combining and interpreting the results of analyses as well as to map both imaging and punctual results onto a 3D proxy of the object. The respondents claimed that it is important to report onto the digital reconstruction, together with the interpretation of the results, also the details of the techniques used and the exact position of the sampling points/areas on the surface.

The level of invasivity of the measurements is considered a key factor for planning and deciding investigation, as well as the safety of the object and of the personnel involved and the ease of understanding and interpreting the outcomes. Replies in the MO (metallic objects analysis) and PA (painting analysis) groups show that the visual observation is still the most used method to make decisions on the need for conservation/restoration along with the in situ application of a combination of non-invasive analyses. To address these issues, the Scan4Reco system is required to enhance the multi-modal approach of investigation and to provide an aid to the comparison of different information and results. On both metal objects and paintings, the choice of sampling points is considered very important by the end users, along with the ability of the investigation techniques to detect appearance, structural, and material changes of the surface with time and/or interventions. The ability of performing several kinds of techniques on the same area/point is also indicated as a key point in order to get complementary information. To address these needs, the Scan4Reco system should point at improving the ability of positioning the measurement

probes on specific areas/points and of going back to the same positions periodically, when a new check of the surface state is necessary.

The experts and the respondents to the questionnaire think that a software tool would be of importance to help people involved in conservation/care of cultural objects. The main expectations concern the capability of the software to extract early warning parameters in order to more efficiently plan interventions, to reconstruct the original appearance of the structure and to predict the effects of certain conservation procedures on the surface's appearance. In particular, the decisions on the conservation treatment to apply and the criteria to choose among the cleaning and protective methods are still mainly based on empirical trials and visual comparison. A Decision Supporting System would be of help to approach the restoration in a more scientific way.

The reproduction of objects via 3D printing (in a similar or in a different material from the original) is envisaged as an innovative tool in the field of CH. A resolution from millimetres down to micrometers is required, depending on the kind of object or the level of detail required for the aim of printing. In 3D printing, the most important features to reproduce are considered to be the 3D geometry of the object, the overall object's material appearance and the color. Interestingly, the most useful application of 3D printing are believed to be the reconstruction of missing parts of artworks and the creation of prints to put in places not matching preservation requirements as harsh environment (supporting conservation and preservation purposes) and making prints for reconstruction of the original context where the artwork originally was (example facades, altars, fountains which do not exist anymore) and the reconstruction of the appearance that the surface had before alteration and degradation (visualization purposes).

A more detailed list of EURs is provided in the next section where each requirement is uniquely identified to assure traceability to subsequent phases in the project life cycle.

6. End-user Requirements

Following the analysis of the users' consolidated and synthesized feedback, the Scan4Reco consortium prepared a list of end user requirements (EURs) that will be used to define the functional specifications of the system.

The requirements are noted as follows:

ID	Name	Priority

- **ID** is the unique ID of the requirement, prefixed with EUR;
- **Name** is the name of the requirement;
- **Priority** is the level of importance of the requirement: Interesting, Important, or Mandatory.

Mandatory requirements are those which, according to users, are absolutely needed otherwise the core value of the system is missing. All these requirements form a coherent set of functionality that can be applied to the Scan4Reco workflow.

Important requirements are those that add the necessary functionalities to ensure that the tool will deliver enough value, but are not necessary for all users.

Interesting requirements bring in benefit if present, but do not hamper the value of the tool if absent. They nevertheless augment the pertinence of the tool and reinforce its potential success.

6.1 (EUR/GR/XX) General Requirements

EUR/GR/01	Documentation on acquisition	Mandatory

All measurements on objects should be documented and the documentation must be easily accessible to the end-user. The acquired data and images must be stored in a specific folder together with metadata (date, motivation for the acquisition, details on the techniques used, position of the area/points investigated). The format of both metadata and data must be readable by the end-user. Where a proprietary software is required to read the data/images, in the case it is not freeware, relevant images or videos or graphs must be saved in a format readable by the end user and stored in the folder.

EUR/GR/02	Paradata documentation	Mandatory

The aim of paradata documentation is to make users able to understand and evaluate interpretation processes that lead to a certain 3D representation of the art object, to the assessment of its state of conservation, to the characterization of the original materials and to evaluation of restoration treatments performances.

To this purpose, enough information should be documented and disseminated to allow computer-based visualisation methods and other investigation techniques outcomes to be understood and evaluated in relation to the contexts and purposes for which they are applied. The information must ensure that audiences can understand what each visualization seeks to represent and what information the acquired data provide on the material properties and the state of conservation of a work of art.

EUR/GR/03	Reduce manual interventions in measuring	Important

All the measurements needed on art objects must be made as quick and easy as possible, in order to increase the efficiency and effectiveness of daily work of conservators and scholars in Cultural Heritage. Both the acquisition of a coarse spatial representation of an object (rough 3D geometric proxy) and all the other punctual, specific measurements must be done by assisting the positioning of probes, which facilitate end-users to acquire digital, multi-modal data. Moreover, to speed up the acquisition, a degree of automatization is wished, like the automatic setting of system parameters (number of acquisitions, spectral range, laser power and so on).

EUR/GR/04	Safety of operation	Mandatory

All measurement devices and procedures should be designed to increase safety of operation and avoid the risk of damage of cultural objects.

The work of art cannot be automatically moved to fit the focus/working distance of the probes. A suitable, steady support must be chosen where the object is put during the acquisition. The power of laser-based probes must be properly tuned in order to avoid any damages to the materials (pigments, varnishes, binding media, dyes, etc.) of the surface under investigation. No residuals of chemicals or labels must be left on the object surface because of acquisition and measurements.

6.2 (EUR/MC/XX) Material and surface appearance characterization

During a restoration or monitoring work, a very important need for conservators is to have as much as possible insights into the behavior of pictorial and metallic materials, including

their physical chemical properties, the associated ageing effects and the results of restoration intervention. In their daily activity, scholars usually apply scientific methods to check the surface structure and appearance, as well as to identify the various material properties of surface and underlying layers in order to characterize the state of conservation of an artwork, to classify the level of preservation, and to make predictions about the future.

In this scenario, it is of extreme importance to have tools to produce **digital representations and models of visual surface appearance and (physical) material properties, and to understand how they evolve over time and under particular environment conditions.**

To obtain repeatable and reliable data and models and to check the goodness of the developed representation, it is necessary to perform such studies on mock-ups prepared in the laboratory and aged under controlled conditions.

A reliable description of both the surface and sub-surfaces properties can be achieved through:

- Acquisition of a set of signals on mock-ups prepared on purpose
- Transformation of the data into a meaningful and objective digital representation
- Evaluation of the digital representation accuracy on mock-ups prepared in a controlled way

The following EURs will list the specific needs of conservators and conservation scientists in terms of material and surface appearance characterization.

EUR/MC/01	**Standardized preparation of material samples/mock-ups**	**Important**

The preparation of samples for the simulation of dynamic processes (such as ageing or restoration treatments) must be done taking into account the artistic techniques and the composition of the past. In order to have meaningful mock-ups of painted and metal artefacts, the right techniques of applying preparation and painting layers and of post cast working and finishing must be known and applied.

End-users need that the effects of restoration and maintenance treatments, as well as the application of layers of protective, finishing, over-painting materials be as faithful as possible in order to provide real, complex systems for studying. To obtain that, the samples must have a suitable size.

EUR/MC/02	**Acquisition and digital representation of surface structure and appearance of material samples**	**Mandatory**

For documentation, preservation and archaeometric purposes, EUs need to have a description of the outmost surface structure and appearance in a quantitative and objective way.

The superficial visual features of painting and metal surfaces have been ranked by the questionnaire respondents as follows:

- regularity of 3D microstructure (texture)
- colour of opaque or glossy parts
- opaque, glossy or mirror-like behaviour
- micro distortion that the object produces when reflecting the surrounding environment, or how it diffuses light
- level of roughness
- level of outer layers transparency

EUR/MC/03	Acquisition and digital representation of sub-surface physical and chemical material properties	Mandatory

Information about the physical and chemical features of objects are very important to cultural heritage scholars. Since many CH objects have a multilayer subsurface structure, EUs need to know the stratigraphy features in the as less as possible invasive way, with particular stress on (as ranked by the questionnaire respondents):

- Molecular and elemental composition of the layers
- Morphology of the layers
- Number of superimposed layers
- Microstructure of the alloy
- Adhesion and cohesion of the layers
- Presence of cracks and detachments
- Thickness of the layers

These features can be related to archaeometrical and conservation aspects such as: manufacturing technique applied by the artist, presence of not original layers due to past restorations, presence of coatings, degradation phenomena.

EUR/MC/04	Inducing changes of surface structure, appearance and chemical-physical properties	Important

The surface of CH assets as well as their chemical-physical properties undergoes changes due to different factors. General factors affecting the surface changes of painting and metal objects are (as ranked by the questionnaire respondents):

- Temperature and relative humidity cycles
- Restoration procedures (cleaning, application of protective coatings etc.)
- Exposure to outdoor environmental agents
- Interaction with UV radiation
- Chemical reactions with pollutants
- Application of coating or over-painting layers
-

The impact such factors have on the CH objects is strongly related to display conditions and to restoration and maintenance operations. Therefore, it is of fundamental importance to provide decision makers with suitable tools to support their exhibition and preservation strategies.

EUR/MC/05	Characterize and model different materials or material states based on surface appearance	Mandatory

EUs need to have a characterization of a material state and an estimation of how it degrades over time and after restoration intervention. Through the use of superficial measurements of mock-ups properties at different level of conservation, such as multi-spectral color, roughness, normal distribution, or micro-geometry, it will be possible to model surface appearance changes as a function of both time and restoration intervention. Moreover, this material characterization can be used to support the visual classification of different materials or different states of conservation of the same material, which is a task that curators, scholars and end-users in cultural heritage daily perform. EUs need a tool that can help discriminate different materials or different states of the same material, by comparing

quantitative measurements of the superficial appearance. This comparison must produce similarity estimation between two surface appearance representations, a numerical distance that represents how far the materials or states of conservation are. Moreover, given a database of surface appearance representations, the tool must also be able to find the most similar occurrence(s) within it. This classification task helps end-users to make informed decision on planning maintenance or restoration operations.

EUR/MC/06	Characterize and model different materials or material states based on sub-surface physical and chemical properties	Mandatory

EUs need to have a characterization of a material state and an estimation of how it degrades over time and after restoration intervention. Through the use of sub-surface physical and chemical measurements of mock-ups properties at different level of conservation, it will be possible to model material changes as a function of both time and restoration intervention. Moreover, this material characterization can be used to support the classification of different materials or different states of conservation of the same material, which is a task that curators, scholars and end-users in cultural heritage daily perform. EUs need a tool that can help discriminate different materials or different states of the same material, by comparing in a quantitative way measurements of the thickness and of composition of sub-surface structure. It means that the tool must analyze and compare thickness variations and changes of the features in the XRF, IR and Raman spectra due to aging, restoration treatments, interaction with environmental factors. This comparison must produce a similarity estimation between two stratigraphic representations, a numerical distance that represents how far are the materials or their states of conservation. Moreover, given a database of stratigraphic representations, the tool must also be able to find the most similar occurrence(s) within it. This classification task helps end-users to make informed decisions on restoration/maintenance plans and to better understand the qualitative and quantitative effects of art care operations. Also a prediction of the time life of the protective coating would be very useful for collections care.

EUR/MC/07	Virtual explorations of replicas of mock-ups	Important

End-users need visualization techniques to inspect the surface and volumetric structure of a material. Visual inspection through virtual reality navigation and illustrative rendering helps to understand the heterogeneous nature and complex structures of cultural heritage objects. It also improves the possibility of a qualitative identification of broad and varied classes of materials, to understand their molecular or macro composition, and to have, beside measurements and models, a deeper visual insight into their degradation mechanisms over time. The visual and virtual replication of mock-ups prepared in laboratory in a controlled way is useful to give information about the prediction and recreation of their future superficial appearance. This will help also in choosing the most appropriate treatment for cleaning and coating processes.

EUR/MC/08	Real-world replication of mock-ups using 3D printing	Important

End-users benefit from 3D physical replication devices and methodologies in order to inspect the real-world replicas of surface appearance, surface geometry and volumetric structure of a material. New 3D printers can use a larger set of pre-defined multi-materials to convey a more realistic real copy of objects. For their works, conservators need that those devices reproduce as far as possible real surface morphology and optical properties of chosen

materials. After the preparation, acquisition and characterization of the mock-ups, which contain different materials treated with different artificial ageing and restoration interventions, end-users ask to produce real-world 3D printed replicas of such specimens. The 3D prints of mock-ups prepared in laboratory in a controlled way are useful to give information about the prediction and recreation of their future superficial appearance. This will help also in choosing the most appropriate treatment for cleaning and coating processes.

6.3 (EUR/MO/XX) Metallic object analysis

The study of metallic objects is of great importance for scholars, curators and restorers in cultural heritage field. By analyzing surface morphology, texture and surface appearance, as well as compositional features, end-users are able to infer various types of hypotheses about those artworks, such as the manufacturing techniques and their changes over centuries or among workshops, the kind of patina layers applied on the surface, the existence of different patina or finishing/protection coatings on the same object. Other information useful to conservation community concern the occurrence of alteration processes such as bronze corrosion or silver tarnishing. Finally, in the conservation practice it is fundamental to have some scientific tools to choose among various processes and to make predictions on the effect of the materials and procedures applied.

Nevertheless, the replies to the EU questionnaire show that the assessment of the need of conservation of objects is still made mostly on the base of visual observation.

The following EURs list the needs of conservators and general end-users in terms of new/advanced useful tasks or best practices to improve the analysis of metallic objects.

EUR/MO/01	**Metallic object dimensions, shape and environment**	**Important**

CH metal objects cover a very broad range of dimensions.

Most outdoor bronze sculptures were meant to celebrate saints and historical figures such as rulers and leaders and typically are full-length, human size. They are round objects and can have different poses of the arms, robes and vests with folders and decorations. Among indoor objects, little sculptures made as reduced-scale reproductions of big-scale antique sculptures with the aim to be picked up. This typology of statue is very spread around museum collections: they are round copper-based statues few tenths of centimeters high.

Silver objects made for worship purposes have dimensions in the range of 30-60 cm of height and 30-40 cm of width, with a thickness less than a cm.

EUs need to acquire and investigate regions of interest on sculptures and reliefs, which are selected taking into account their accessibility, their flatness, their orientation, their exposure to rainfall and pollutants.

Users may use the system not only in museums or in laboratory but also outdoor, for example on a scaffold. The capability of the system to perform in-situ investigation is considered important.

EUR/MO/02	**Collection of a series of local multi-modal measurements across a metallic object surface**	**Mandatory**

The questionnaire replies show that for the study of metallic objects, end-users typically acquire a set of local measurements of the metal properties. A multi-modal acquisition of

both compositional and optical characteristics is an important need since only the combination of data from different investigation techniques allows getting to a satisfactory understanding of the metal characteristics and alteration. The choice of sampling points is a critical issue. Experts choose them in such a way to be meaningful to provide hints on the working technique and representative of certain degradation and alteration processes. At least, also the ease of approaching the surface with the probes is a crucial issue in this chooses.

EUs require an automated system to help positioning the various probes in an easy way in order to get different kind of information (composition, texture, thickness, roughness) on the same sampling point.

Furthermore, for monitoring purposes EUs need to measure the same point periodically and they require a tool to help them to position the probes on the same points.

Since typical EUs of such a system have different characteristics in term of educational level, language, experience and technical expertise, this imposes important constraints on the system ease of use.

EUR/MO/03	**Checking changes of metallic objects**	**Mandatory**

Metal objects are prone to changes for the interaction of their surface with pollutants and coating with protective films is needed in order to stop or slow down corrosion and loss of surface features. Other changes occurring on CH metallic objects are due to restoration treatments, in particular cleaning is a very tricky but unavoidable phase. End-users need to identify markers of the presence of different artistic patina and/or patches of different finishing materials, the failure of the protective coatings, the early inset of corrosion products, the level of cleaning achieved. Possible indicators of such changes are the surface texture, the molecular composition, the thickness of the external layer of patinas, and the presence of cracks or detachments between the patina and the substrate. Measurements of those indicators can increasingly help experts to trace back the conservation history of the object, curators and collection supervisors to make informed maintenance plans and conservators to make decisions on the extent and width of their cleaning action.

EUR/MO/04	**Interactive exploration of analysis results on metallic objects**	**Important**

The end-users need a tool to explore the various analyses performed on a metallic object using a user-interface capable to provide simplified access to the documentation. The interface should be capable to provide access to all the punctual analyses made, to establish relations among them, and to help taking decisions on future analyses as well as on conservation issues.

In order to visually simplify the interface, the shape of the object should be used to simplify information access. Given a three dimensional geometric proxy and all the measurements of a metallic object mapped onto it, the end-users need visualize on the coarse 3D proxy the positions where particular punctual measurements have occurred in the past. They must be able to select those measures, and see specific information for each measure (e.g., graphs, maps, numerical values). Moreover they must be able to perform sub-region selection that extracts all the punctual measurements within a region. The possibility to insert additional comments/annotations on the 3D proxy and within local data, although not mandatory, would be interesting for communication and documentation of research findings/hypothesis about studied metallic objects.

EUR/MO/05	Exploration of the evolution of single-material metallic objects through spatio-temporal simulation	Mandatory

Given an object made of a single material, end-users need to understand how that object will evolve due to some ageing effects or restoration treatments. Starting from the acquired low-resolution geometry and the procedurally modeled material, end-users will be provided with a spatio-temporal simulation of the evolution of the object conditions, in order to make reliable prediction on the object' behavior over time and the effect of the restoration treatments.

EUR/MO/06	Replication of single-material metallic objects using 3D printing	interesting

Given an object made of one material, its digital representation of the geometry and the model of its material, end-users find helpful to produce real-world 3D printed copy of it. This can be done at the current state, at possible level of ageing or after a simulated restoration treatment. Given the model of the material, its behavior will be simulated in a pre-printing step using procedural modeling coupled with the ageing/treatment characterization for that particular material. The end-users will benefit from that since they can obtain representation of the object in an earlier stage of its lifetime (for example with the original patina laid on the whole surface or without the bronze corrosion green/black salts and deposit). Moreover, given a multi-modal representation of the material, end-users find helpful to produce real-world 3D printed replicas of this material that highlights its features in an illustrative, non-photorealistic manner. This will be of help for producing replicas to be shown in exhibits when the object is not allowed to move or to be used in reconstruction of the original contexts which a work of art was designed for. This will be also useful to complete some missing parts, for example in the case of archaeological findings.

6.4 (EUR/PA/XX) Painting analysis

The study of painting is of great importance for scholars, curators and restorers in cultural heritage field. By analyzing pigments, the surface appearance and the volumetric structure underneath, end-users are able to infer various types of hypotheses about those artworks, such as the time of creation, the conservation status, deformations, the degradation and alteration of organics such as binding media and varnishes, and the artist's technique. They are able to discover covered areas of paint, repainting and retouches, incisions and marks, lacunas, missing parts, micro-defects and regions susceptible to damage. The following EURs will list the needs of conservators and general end-users in terms of new/advanced useful tasks or best practices to improve the analysis of paintings.

EUR/PA/01	Painting acquisition environment	Mandatory

Movable paintings, usually on canvas and wood supports, are displayed in museums, private collections and churches or monasteries. End-users require that large size paintings are left on site for acquisition. Moving a large size painting from its usual displaying place to a lab/room for acquisition requires a steady support such as an easel and staff allowed doing that.

EUR/PA/02	Collection of a local multi-modal measurements across a painting	Mandatory

In the study of paintings, end-users typically acquire a set of local measurements of paint/underpainting properties. The choice of those points is made according to different colors and/or the presence of some degradation patterns such as discoloration, yellowing,

flaking. The choice is also underpinned by inspection via imaging techniques, like raking light, UV and IR images. These sampling points and the corresponding measurements must be repeatable within a certain level of confidence or tolerance, which typically depends on a trade-off between scholars' needs and instrument accuracy. End-users require cooperating with technical partners to define in detail those measuring elements.

Since typical EUs of such a system have different characteristics in term of educational level, language, experience and technical expertise, this imposes important constraints on the system ease of use.

EUR/PA/03	**Mapping of local/punctual measurements onto a global proxy of a painting**	**Mandatory**

In order to organize all the punctual measurements performed on paintings, the end-users need a unique and global reference frame onto which the local, punctual data has been mapped. End-users require a coarse two dimensional geometric proxy to index all the other measurements of painting.

EUR/PA/04	**Construction of a stratigraphy of visible and non-visible paint layers in a painting**	**Interesting**

Paintings are typically made by a series of layers, going from the panel substrate (e.g. wood) to the outermost layer of varnish. It is of interest the study and understanding of the inner structure of those layers, both qualitative and quantitative. The conservators need to know the stratigraphy of the painting, and use a schematic diagram that not only can highlight the presence of varnish, intermediate preparation layers, some particular pigments (e.g., Red Ochre, Carbon Black, Lead White), and the presence of pollutant-dirt within the paint, but also that can provide a quantitative measure of the thickness of those layers. The knowledge of the stratigraphy can help in revealing the art school of the painting, the presence of not original, superimposed layers, the ongoing processes of layers detachments or flaking, the residues of old restoration treatments.

EUR/PA/05	**Interactive exploration of analysis results on paintings**	**Interesting**

The end-users need a tool to explore the series of analyses made on painting in a virtual environment. Using the 2D proxy of the painting as a reference frame, users should be able to access areas where a stratigraphic model has been made. Specific tools should highlight particular characteristics (e.g., classification of pigments or highlighting of underdrawings).

Given a two dimensional geometric proxy and all the measurements of a painting mapped onto it, the end-users need to perform some operations during the analysis. In particular, they need to be able to visualize on the coarse 2D proxy the positions where particular punctual measurements occur. They must be able to click on those points and open a viewer for each particular measurement/data. Moreover, they must be able to perform sub-region selection that extracts all the punctual measurements within it. The possibility to insert additional comments/annotations on the 2D proxy and within local data, although not mandatory, would be interesting for communication and documentation of research findings/hypothesis about studied paintings.

EUR/PA/06	**Exploration of the evolution of paintings through spatio-temporal simulation**	**Mandatory**

People involved in collection care and conservation needs to know how the various components of a painting evolve in time in order to plan restoration and maintenance plans. Scholars would also like to know how the painting surface was like when it was created by the artist, before the application of additional painting layers and/or of past restoration processes (for example, too aggressive cleaning, application of thick varnish layers, cut of some parts to fit in a frame or a niche). The reconstruction of a spatio-temporal evolution of the painting will be useful to end-users both for conservative and archaeometric purposes.

EUR/PA/07	**Use 3D printing to explore real-world replicas of paintings**	**Mandatory**

Given a painting, its digital representation of the geometry and the model of its material or its volumetric structure, end-users find helpful to produce real-world 3D printed copy of selected areas of it. This can be done at the current state, at possible level of ageing or after a simulated restoration treatment. Given the model of the material, its behavior will be simulated in a pre-printing step using procedural modeling coupled with the ageing/treatment characterization for that particular material. The end-users will benefit from that to get an actual version of the painting or of a portion of it after a simulation of cleaning and to make decision on its effectiveness. Moreover, given a multi-modal representation of the material, end-users find helpful to produce real-world 3D printed replicas of this material that highlights its features in an illustrative, non-photorealistic manner. The illustrative 3D printing of the volumetric structure of the stratigraphy will help in demonstration and training events.

6.5 Other requirements

EUR/OR/01	**Create a Decision Support System to help scholars in the planning of restoration interventions**	**Mandatory**

A very huge amount of data can be related on a work of art, like 3D models, ageing factors, ageing models, analytical data about physical and chemical features, markers of the presence of different artistic materials and the end-user's real-time commands (via interaction). Therefore, end-users need an oriented Decision Support System (DSS) that has the mission to process all relevant data, to export in a human-comprehensive way the actions need to be taken for better preservation and conservation of the cultural object under study. It's a computer-based information system that stored simple conservation instructions in a dedicated database and it will then use them combinatorically to extract complex conservation related suggestions. The objectives of a DSS is to produce possible decisions by analyzing the data, in an intelligent and fast way a human being cannot do in reasonable time. The work of conservators will be then facilitated by using a ranking of several key suggestions, produced by DSS, which the conservator can evaluate in order to select the most suitable intervention for the conservation of a CH.

References

[1] Scan4Reco Grant Agreement Annex I – “Description of Action” (DoA)

[2] 3D-COFORM project (FP7): Tools and expertise for 3D Collection Formation

[3] GRAVITATE project (Horizon 2020)

[4] CHARISMA project (FP7): Cultural Heritage Research Infrastructures

[5] IPERION-CH project (Horizon2020): *Integrated Platform for the European Research Infrastructure ON Culture Heritage*

Annex I: End-user Questionnaire data

The respondents were 25 conservators/restorers, 21 conservation scientists and 7 curators. The following tables show the affiliation of respondents in each group.

Regardless their background, the most of the respondents are from Italy (29), USA come after with 6 replies while the other respondents spread over 7 European countries, as shown in Figure 1.

Table 1: affiliation and country of respondents

Number of respondents	Affiliation	Country
1	Art-test sas	Italy
2	ICVB-CNR	Italy
2	INO-CNR	Italy
1	Yale University Art Gallery	USA
3	CATS-SMK	Denmark
1	IPCE	Spain
1	National Institute for Nuclear Physics and Engineering	Romania
1	IFAC-CNR	Italy
1	University of Perugia	Italy
1	KIK-IRPA	Belgium
2	Soprintendenza Archeologia della Toscana	Italy
1	National Museum of Romanian History	Romania
2	The National Gallery	UK
1	Institute for the Preservation of Cultural Heritage, Yale University	USA
1	S.T.Art-Test di S. Schiavone sas	Italy
1	University of Catania	Italy
1	Haute Ecole Arc Conservation-restauration	Switzerland
1	Benaki Museum	Greece
1	National Gallery - Alexandros Soutzos	Greece
1	Courtauld Institute of Art	UK
1	National Gallery of Athens	Greece
1	Polo Museale dell'Emilia Romagna	Italy
1	Soprintendenza Belle Arti e Paesaggio di Siena, Grosseto e Arezzo	Italy

1	Folklife & Ethnological Museum of Macedonia – Thrace	Greece
1	Byzantine & christian museum	Greece
1	Fondazione Scienza e Tecnica	Italy
1	Statens Museum for Kunst	Denmark
12	Free- lance conservators	Italy
1	Milazzo Restauri srl	Italy
1	Salvioli Nicola Restauro Conservazione Documentazione	Italy
1	Civic Archaeological Museum of Bologna	Italy
1	Dartmouth College	USA
1	German Maritime Museum	Germany
1	Yale Peabody Museum	USA
1	National Museum of Capodimonte- Napoli	Italy

Table 2: respondents in the curators group

Number of respondents	Affiliation	Country
1	Yale Peabody Museum	USA
1	Dartmouth College	USA
1	Civic Archaeological Museum of Bologna	Italy
1	Fondazione Scienza e Tecnica	Italy
1	Folklife & Ethnological Museum of Macedonia – Thrace	Greece
1	Polo Museale dell'Emilia Romagna	Italy
1	Benaki Museum	Greece

Table 3: respondents in the conservators/restorers group

Number of respondents	Affiliation	Country
1	German Maritime Museum	Germany
1	Statens Museum for Kunst	Denmark
1	Milazzo Restauri srl	Italy
1	Centre for Art Technological Studies and Conservation	Denmark

1	Salvioli Nicola Restauro Conservazione Documentazione	Italy
1	Byzantine & christian museum	Greece
1	Soprintendenza Belle Arti e Paesaggio di Siena, Grosseto e Arezzo	Italy
1	The National Gallery	UK
12	Free-lance conservator	Italy
2	Yale University Art Gallery	USA
1	National Gallery of AThens	Greece
1	Courtauld Institute of Art	UK
1	National Museum of Capodimonte	Italy

Table 4: respondents in the conservation scientists group

Number of respondents	Affiliation	Country
1	Yale University Art Gallery	USA
2	Soprintendenza Archeologia della Toscana	Italy
1	Art-test sas	Italy
2	Centre for Art Technological Studies and Conservation	Denmark
4	Italian National Council of research	Italy
1	Institute for the Cultural Heritage of Spain	
1	National Institute for Nuclear Physics and Engineering	Romania
1	University of Perugia	Italy
1	University of Catania	Italy
1	KIK-IRPA	Belgium
1	The National gallery	UK
1	Institute for the Preservation of Cultural Heritage, Yale University	USA
1	S.T.Art-Test di S.Schiavone sas	Italy
1	Haute Ecole Arc Conservation- restauration	Switzerland
1	National Gallery A. Soutzos Museum	Greece
1	National Museum of Romanian History	Romania

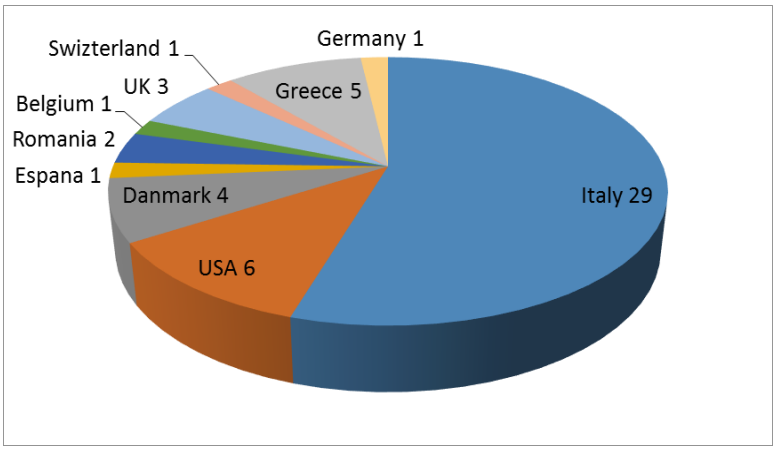


Figure 1: number of replies per country

As for the affiliation, most of the respondents belong to public institutions and 21% to private companies or are free-lance restorers. Most of the public institutions are directly involved in art objects collections and management (Table 4) while some respondents in the group of conservation scientists belong to universities or research centers.

Table 5: distribution of respondents among public institutions

Public institutions involved in art objects collections and management	Number of respondents
Yale University Art Gallery- USA	4
Soprintendenze -Italy	3
The National Gallery of London- UK	2
Byzantine & christian museum - Greece	1
German Maritime Museum -Germany	1
Statens Museum for Kunst - Danmark	1
Yale Peabody Museum - USA	1
Dartmouth College- USA	1
Civic Archaeological Museum of Bologna- Italy	1
Fondazione Scienza e Tecnica-Italy	1
Folklife & Ethnological Museum of Macedonia – Thrace	1
Polo Museale dell'Emilia Romagna-Italy	1
Yale Peabody Museum- USA	1
Centre for Art technological Studies and Conservation- Danmark	4
Institute for the cultural Heritage of Spain	1
KIK-IRPA- Belgium	1
Institute for the Preservation of Cultural Heritage, Yale University- USA	1

National Gallery of Athens- Greece	1
Courtauld Institute of Art- UK	1
Benaki Museum- Greece	1
National Gallery- Alexandros Soutzos Museum	1
National Museum of Romanian History	1
National Museum of Capodimonte	1
Universities and research centers	
National Institute for Nuclear Physics and Engineering-Romania	1
University of Perugia- Italy	1
Institutes of the Italian National Council of Research	5
University of Catania-Italy	1
Haute Ecole Arc Conservation- restauration- Switzerland	1

For many questions a check list was provided in order to facilitate the answers. A multiple choice of boxes was allowed (see Annex II). End-users replied to answers concerning the field they are experienced in and skipped some questions on aspects they do not deal with in their work. Some questions were most left, probably due to the lack of specificity of the question. They were questions on the kind of objects and size the respondents wish to print.

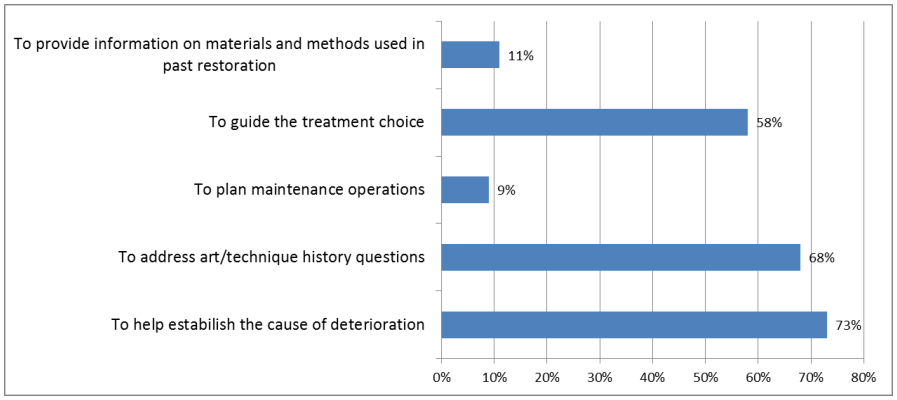
Data were processed separately for each group of end-users. In general, the responses agree regardless the category of respondents. Some relevant differences among groups of respondents are reported in the following for questions MO.b, PA.b, DS.a, DS.c

It is interesting to notice that conservators and conservation scientists replies generally agree on technical improvements, while the curators replies are more oriented toward a better visualization of the results of acquisition and less interested to, for example, the positioning of the probes or the careful selection of acquisition areas/points (MO.b and PA.b).

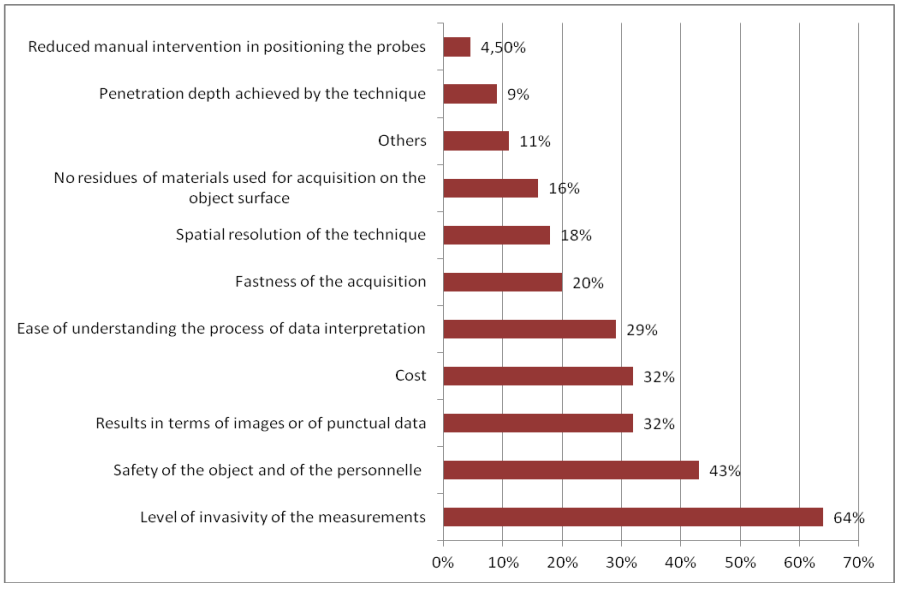
Similarly, in DS.a replies we observe that conservators and conservation scientists agree on the usefulness of predictive software is mainly to predict changes due to weathering and/or to restoration treatments, while curators are more interested in increasing the overall knowledge of the materials of the object and in reconstructing the original appearance of the object.

Questions on General Requirements (GR)

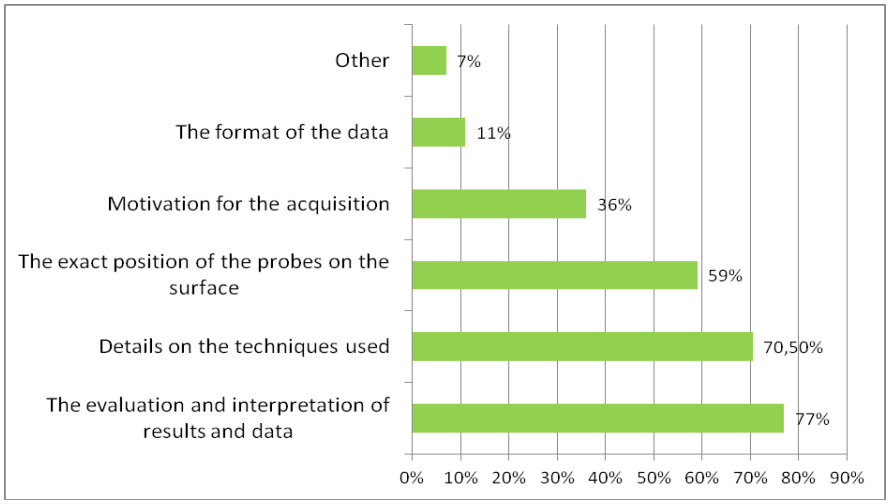
GR.a - The main aims of performing scientific investigation on artworks are:



GR.b. - What are the most important requirements you take into account when you plan investigation/measurements on artworks?

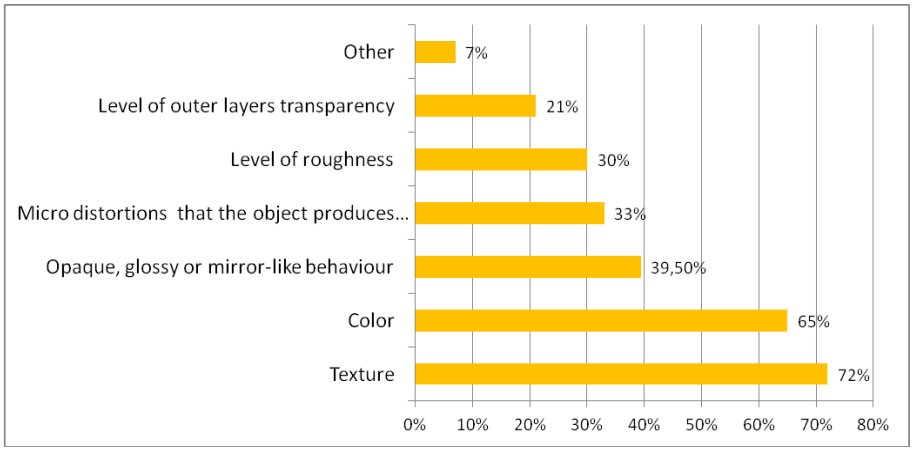


GR.c - What is important to document and to record about the acquisition/measuring phase?

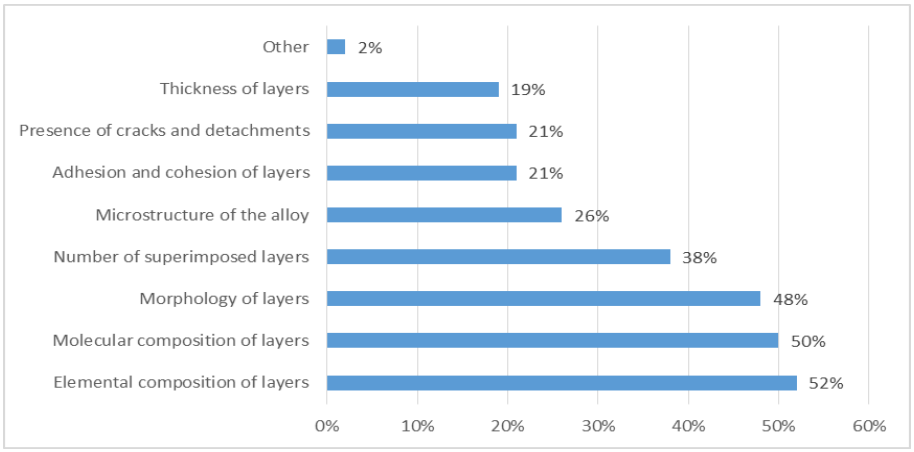


Questions on materials characterization (MC)

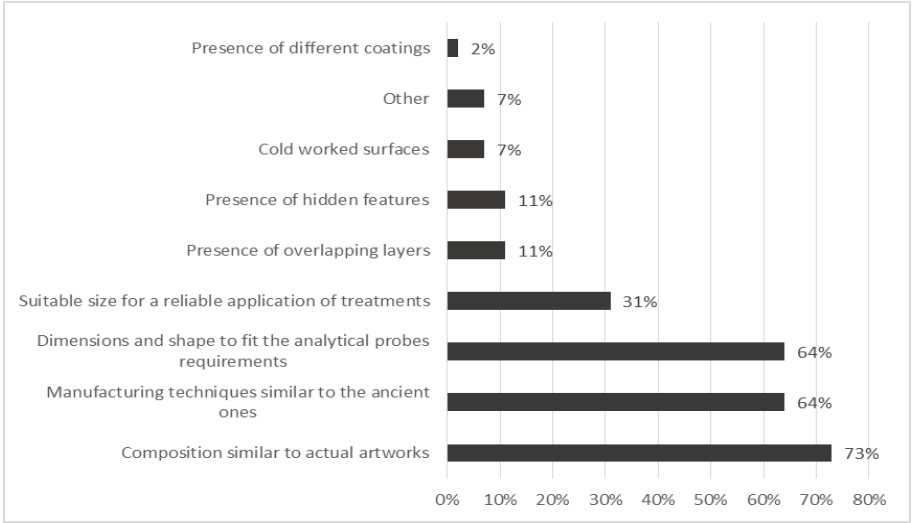
MC.a - Which of the following visual features of paintings and metal artefacts are fundamental to characterize their surface?



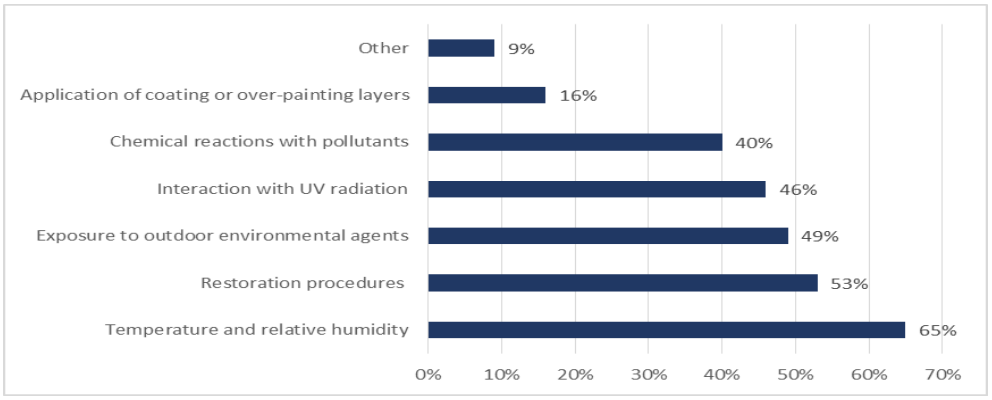
MC.b - Which of the following physical and chemical material properties of paintings and metal artefacts are fundamental for their characterization?



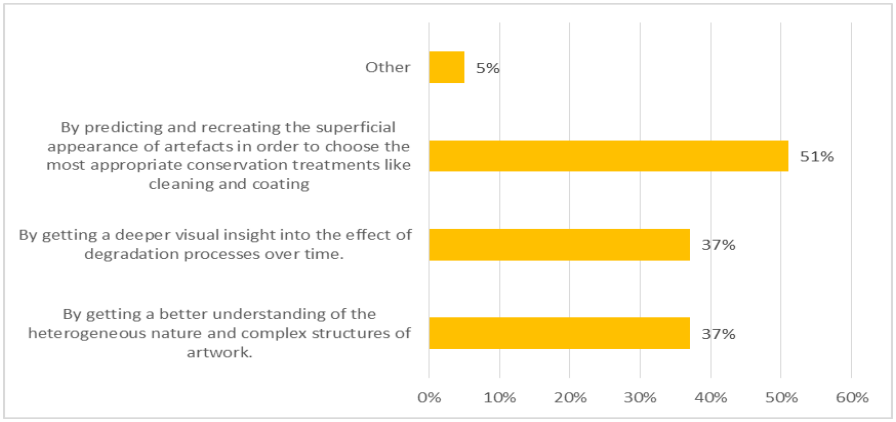
MC.c - To prepare reliable mock-ups of metal art objects and paintings it is important to have



MC.d - Which of the following factors or conservation processes mainly determine changes of painting and metallic surfaces?

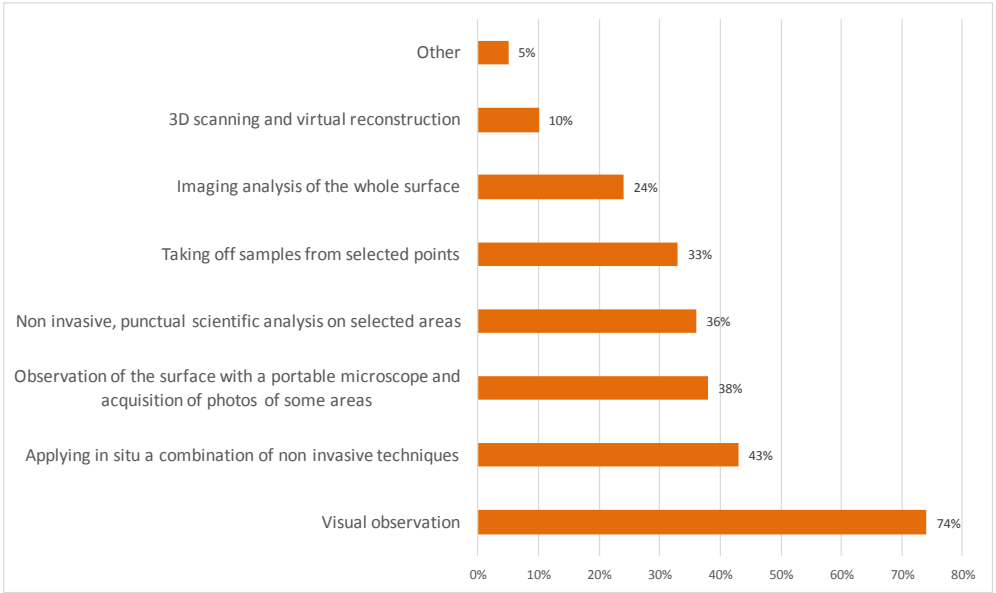


MC.e - How virtual replicas and real replications of mock-ups by 3D printing can help in setting up conservation procedures?

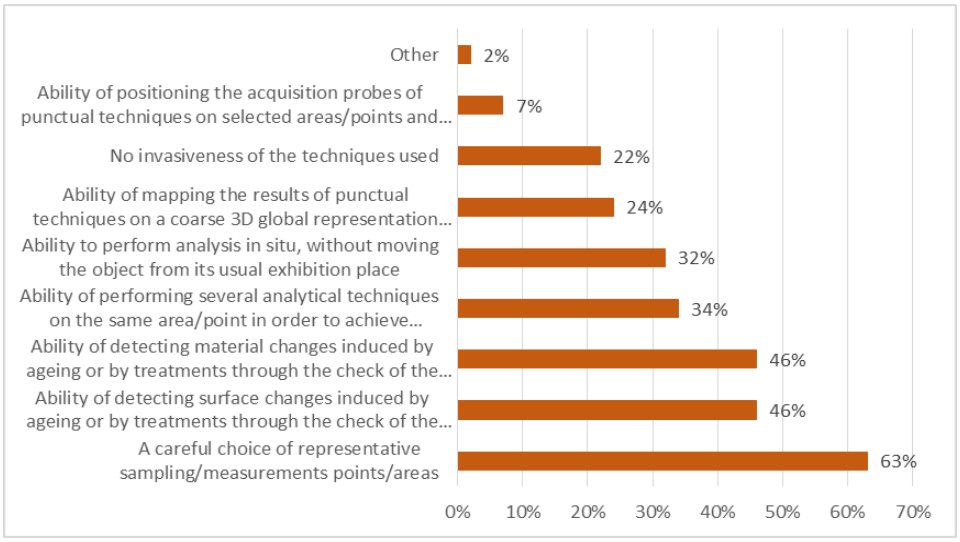


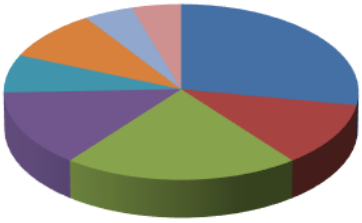
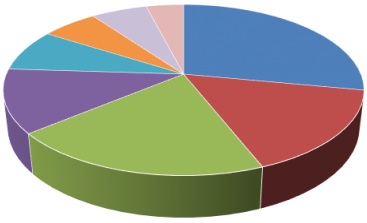
Questions on Metallic Objects analysis (MO)

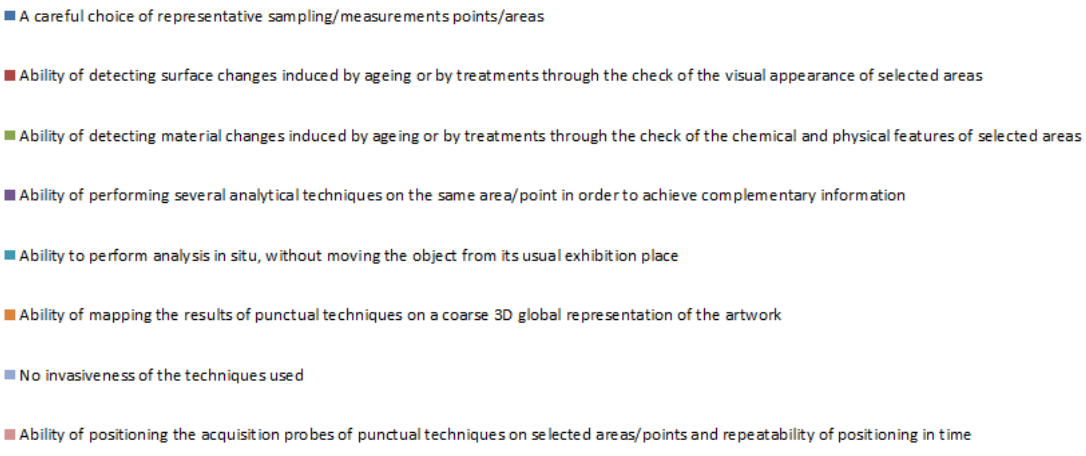
MO.a - How are the objects in need of conservation treatment currently identified?



MO.b - Which of the following requirements are important for investigation of metal art objects?

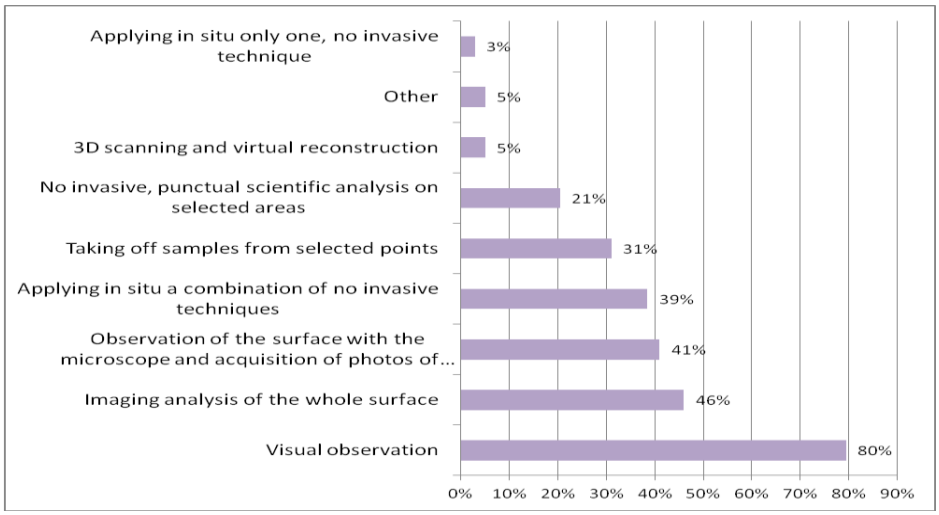


Curators replies	Conservation scientists replies	Conservators replies
		

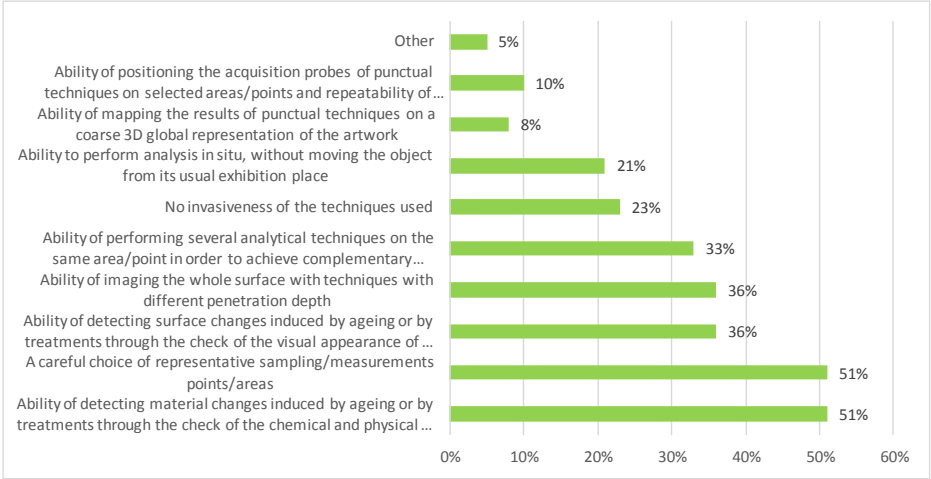


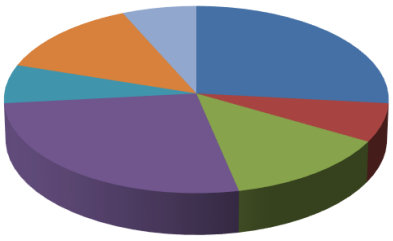
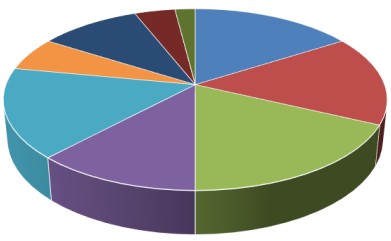
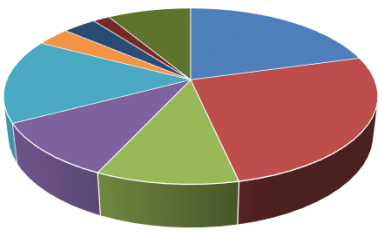
Questions on Painting Analysis (PA)

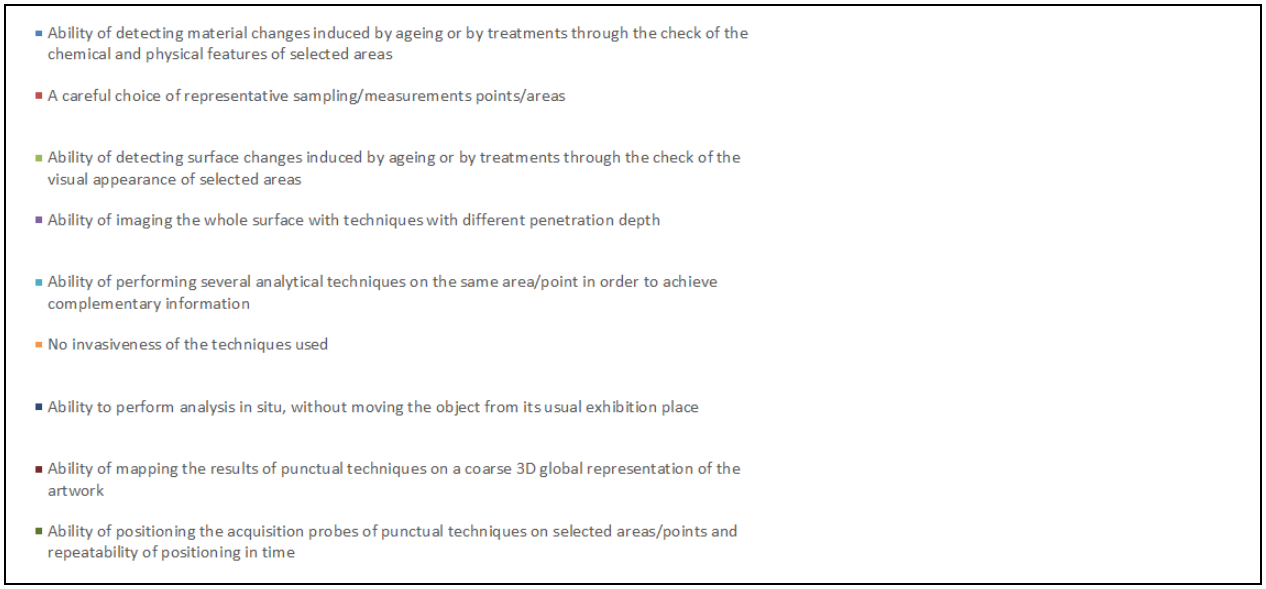
PA.a - How are the paintings in need of conservation treatment currently identified?



PA.b - Which of the following requirements are important for investigation of paintings?

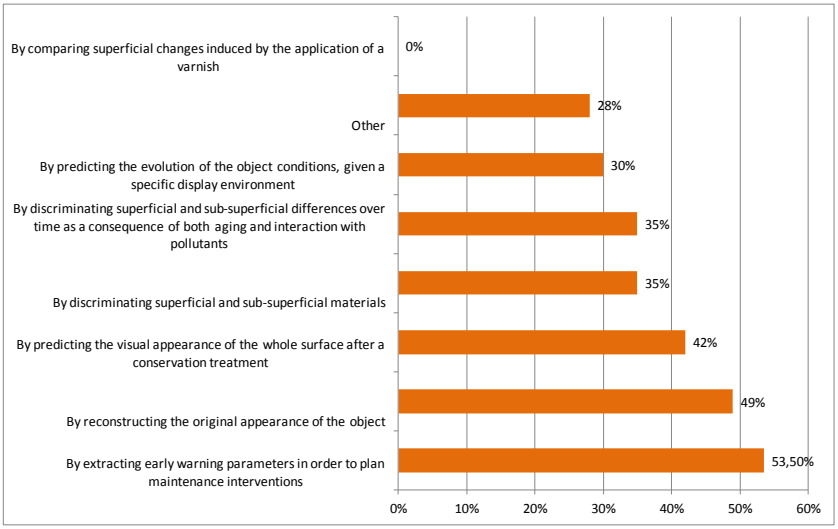


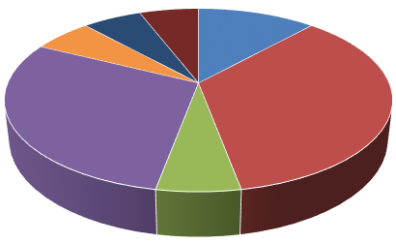
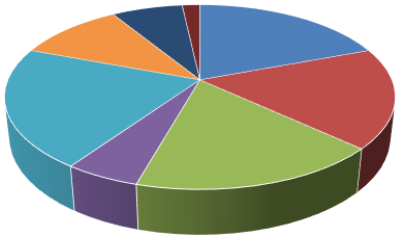
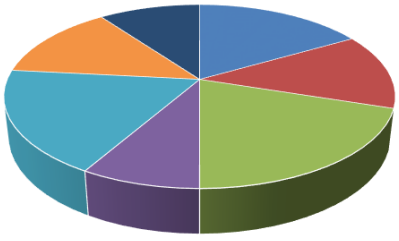
Curators replies	Conservation scientists replies	Conservators replies
		

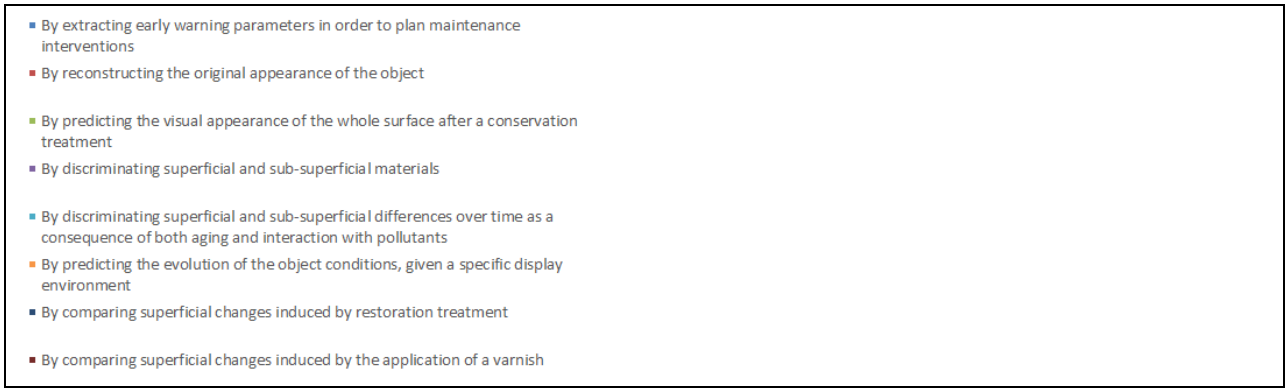


Questions on Digitalization, Simulation and 3D printing (DS)

DS.a - How can a software help people involved in collection care and conservation?



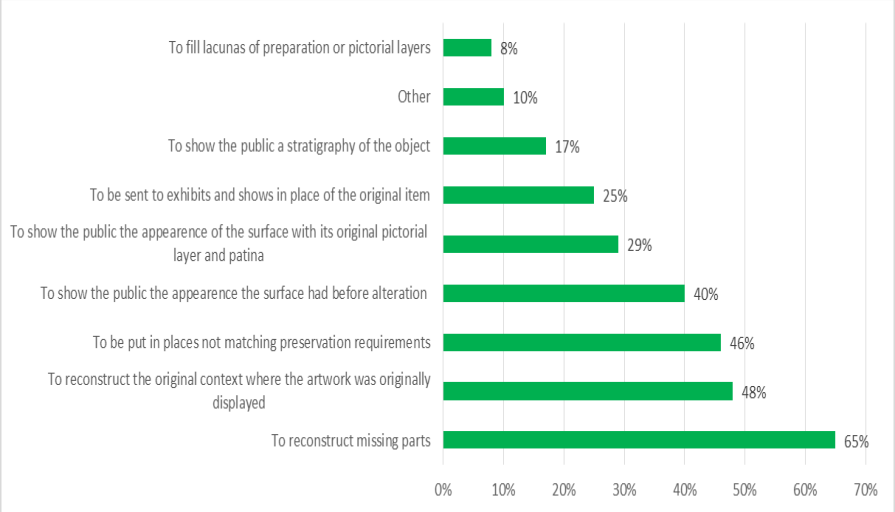
Curators replies	Conservation scientists replies	Conservators replies
		

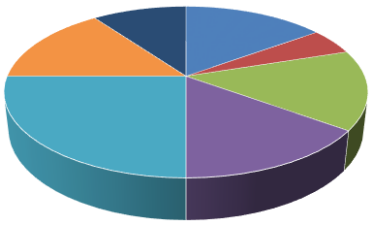
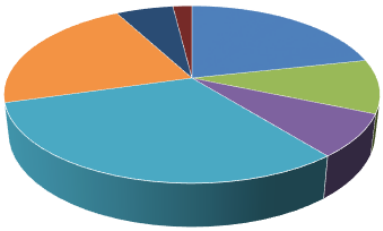
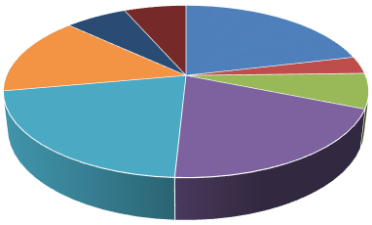


DS.b - Please choose the level of importance for the following aspects regarding reproduction:

	Very important	Important	Nice to have	Not important
How important is an accurate reproduction of the object's 3D geometry	41.5%	36.5%	22%	-
How important is the reproduction of the overall object's material appearance or appearance attributes (color, translucency, gloss)?	38%	40%	17%	5%
How important is the accurate reproduction of color?	56%	27%	12%	5%
How important is the accurate reproduction of translucency?	22%	44%	24%	8%
How important is the accurate reproduction of gloss?	23%	46%	27%	2%
Wood and other materials change appearance depending on illuminating/viewing geometry. How important is the accurate reproduction of this kind of directional reflectance?	29%	42%	29%	2%
Multimaterial 3D printing allows using fully transparent printing material. This can be used for visualizing hidden parts of the objects beneath its surface while preserving the overall object geometry (using the transparent material). This can be also visualized on a display. How important is such visualization by a print?	15%	39%	41%	5%

DS.c -What replicas of artwork by accurate 3D printing can be useful for?



Curators replies	Conservation scientists replies	Conservators replies
		

DS.d- On 3D printing

Which objects would you like to print?

Kind of object	Number of replies
Paintings	12
Sculptures	13
Stratigraphy	2
3D objects	2
Missing parts of sculptures	2
Jewellery items	2
Small archaeological findings	2
Architectonic details	1
Historical scientific instruments	1
Finger and palm prints left in materials (ceramics, lost-wax bronzes)	1

Coins	1
Backings or supports for paintings	1
Glass objects	1

For which purposes you would like to use 3D printing?

Purpose	Number of replies
Visualization	19
Supporting conservation	16
Archiving	5
Documentation	3
Merchandizing	3
Educational	4
Display	6
Studying the technology of works of art	3
Innovative valorisation for blind people	1
Mounts and secondary supports	1
Authenticity investigation	1

How big are the objects you would print?

Size	Number of replies
Meters	6
centimetres	8
from centimetres to meters	12
Variable size	4
Original : several meters, but the scale can be reduced	1
Noticeable reply: Easel paintings vary in size, however representative small areas would be useful, for example, the areas of cleaning tests, estimated one cm square.	

What is the sufficient 3D printing resolution? Which level of details would you like to reproduce by 3D printing?

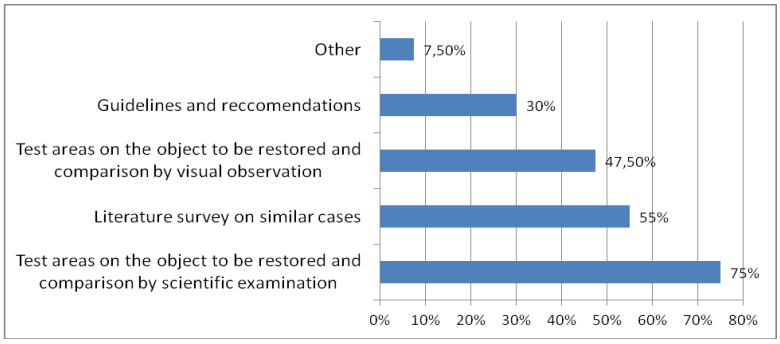
Resolution	Number of replies
micrometers	14
millimetres	18
From hundreds of microns to millimetres	5
depends on the printing aim	2
depends on the subject	2
Noticeable replies: micrometres for paintings, millimetres for sculptures; to model specific localised issues micrometres, to give general impressions millimetres work	

Which materials are the objects you would like to reproduce by 3D printing made of?

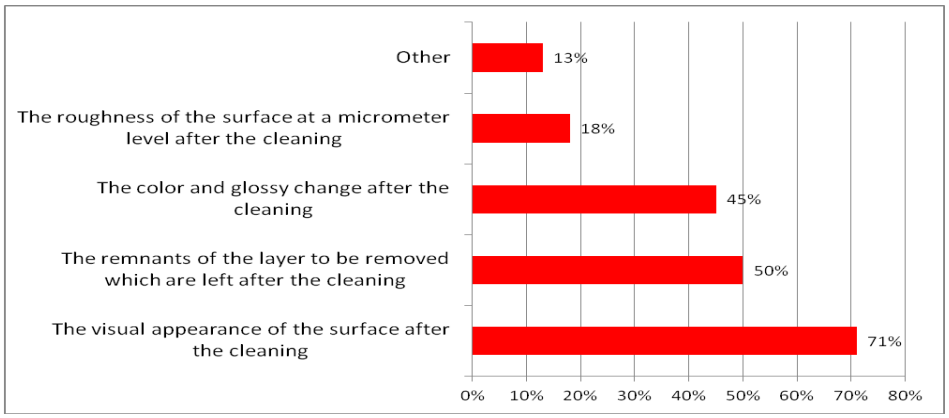
Material	Number of replies
Wood	12
Metal	16
Stone	8
Canvas	5
Jewellery items	2
All the materials	9
Polymaterial items	2
Glass	1
Paper and watercolors	2
Plastics	5

Questions on restoration processes

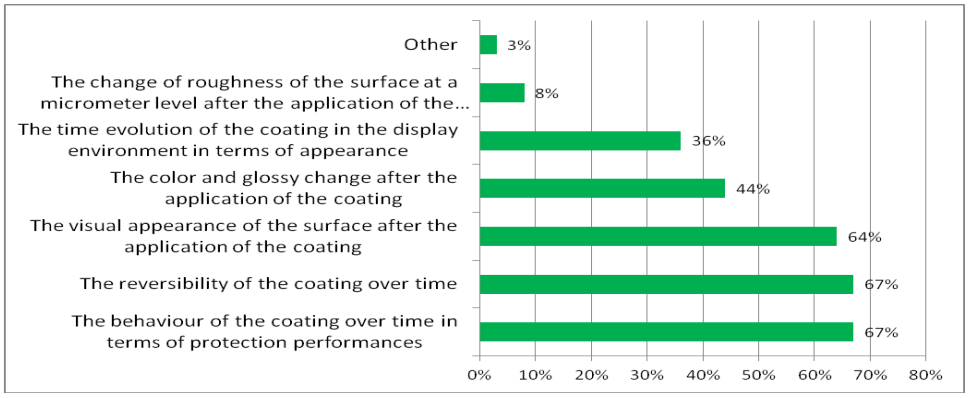
OR.a - What procedure do you use for making decisions on conservation treatments?



OR.b - Which factors do you consider as most important when you choose a cleaning procedure on paintings or on metal objects?



OR.c - Which factors do you consider as most important when you choose a coating to lay on paintings or on metal objects?



Annex II: End-User Questionnaire

Questionnaire on end-users requirements for the EC project Scan4Reco

*Multimodal **Scan**ning of Cultural Heritage Assets for their multimodal digitization and preventive conservation via spatiotemporal **4**D **Reco**nstruction and 3D Printing*

http://scan4reco.eu/scan4reco

About You

Please provide some information about yourself and your organization.

User's Contact

First Name .....

Last Name .....

Email address .....

Organization

Organization name .....

Website ..... http://

Country .....

Your activity and background

☐Restorer/conservator

☐Conservation Scientist

☐Art historian/curator

General requirements GR

GR.a- The main aims of performing scientific investigation on artworks are (select no more than 3 options):

☐ To help establish the causes of deterioration

☐ To address art/technique history questions

☐ To guide the treatment choice

☐ To plan maintenance operations

☐ To provide information on materials and methods used in past restoration

☐ Others…….

GR.b-What are the most important requirements you take into account when you plan investigation/measurements on artworks? (select no more than 3 options)

☐ Fastness of the acquisition

☐ Cost

☐ Level of invasivity of the measurements
☐ Safety of the object and of the personnel
☐ Ease of understanding the process of data interpretation
☐ Spatial resolution of the technique
☐ Penetration depth achieved by the technique
☐ No residues of materials used for acquisition on the object surface
☐ Reduced manual intervention in positioning the probes
☐ Results in terms of images or of punctual data
☐ Others……..

GR.c- What is important to document and to record about the acquisition/measuring phase? (select no more than 3 options)

☐ The exact position of the probes on the surface
☐ Motivation for the acquisition
☐ Details on the techniques used
☐ The evaluation and interpretation of results and data
☐ Format of the data
☐ Others……..

Material and surface appearance characterization MC

The Scan4Reco project includes the preparation of metal and painted samples for the characterization of their surface appearance and material properties and for studying the behaviour of painting materials and metals upon the effect of ageing and conservation treatments.

MC.a- Which of the following visual features of paintings and metal artefacts are fundamental to characterize their surface (select no more than 3 options):

☐ Level of roughness
☐ Texture
☐ Opaque, glossy or mirror-like behaviour
☐ Colour
☐ Level of outer layers transparency
☐ Micro distortions that the object produces when reflecting the surrounding environment, or how it diffuses light
☐ Others…….

MC.b- Which of the following physical and chemical material properties of paintings and metal artefacts are fundamental for their characterization? (select no more than 3 options)

☐ Number of superimposed layers
☐ Thickness of opaque and transparent layers
☐ Molecular composition of layers

□ Elemental composition of layers
□ Microstructure of the alloy
□ Morphology of layers
□ Adhesion and cohesion of layers
□ Presence of cracks and detachments
□ Others……..

MC.c- To prepare reliable mock-ups of metal art objects and paintings it is important to have (select no more than 3 options):

□ Composition similar to actual artworks
□ Manufacturing technique similar to the ancient ones
□ Suitable size for a reliable application of treatments without edge effects
□ Presence of overpainting layers
□ Cold worked surfaces such as chieselled and hammered
□ Presence of different coatings
□ Presence of hidden features such as underdrawings
□ Dimensions and shape to fit the analytical probes requirements
□ Others……..

MC.d – Which of the following factors or conservation processes mainly determine changes of painting and metallic surfaces? (select no more than 3 options)

□ Interaction with UV radiation
□ Temperature and relative humidity
□ Chemical reactions with pollutants
□ Application of coating or over-painting layers
□ Restoration procedures (cleaning, application of protective coatings etc.)
□ Exposure to outdoor environmental agents: rain, wind, deposition of airborne particulate.
□ Others……

MC.e – How virtual replicas and real replications of mock-ups by 3D printing can help in setting up conservation procedures?

□ By getting a better understanding of the heterogeneous nature and complex structures of artwork.

□ By getting a deeper visual insight into the effect of degradation processes over time.

□ By predicting and recreating the superficial appearance of artefacts in order to choose the most appropriate conservation treatments like cleaning and coating

□ Others.....

Metallic objects analysis MO

The Scan4Reco project includes the development of a novel, integrated, multimodal system for investigation of metal art objects.

MO.a- How are the objects in need of conservation treatment currently identified? (select no more than 3 options)

☐ Visual observation

☐ No invasive, punctual scientific analysis on selected areas

☐ Imaging analysis of the whole surface

☐ Taking off samples from selected points

☐ Applying in situ only one, no invasive technique

☐ Applying in situ a combination of no invasive techniques

☐ Observation of the surface with the portable microscope and acquisition of photos of some areas

☐ 3D scanning and virtual reconstruction

☐ Others.....

MO.b- Which of the following requirements are important for investigation of metal art objects? (select no more than 3 options)

☐ A careful choice of representative sampling/measurements points/areas

☐ Ability of positioning the acquisition probes of punctual techniques on selected areas/points and repeatability of positioning in time

☐ Ability of performing several analytical techniques on the same area/point in order to achieve complementary information

☐ Ability of mapping the results of punctual techniques on a coarse 3D global representation of the artwork

☐ Ability of detecting surface changes induced by ageing or by treatments through the check of the visual appearance of selected areas (texture, color, gloss, roughness, micro distortions of the reflected light)

☐ Ability of detecting material changes induced by ageing or by treatments through the check of the chemical and physical features of selected areas (thickness of layers, composition

☐ No invasiveness of the techniques used

☐ Ability to perform analysis in situ, without moving the object from its usual exhibition place

☐ Others.....

Analysis of paintings PA

The Scan4Reco project includes the development of a novel, integrated, multimodal system for investigation of paintings.

PA.a- How are the paintings in need of conservation treatment currently identified? (select no more than 3 options)

☐ Visual observation
☐ No invasive, punctual scientific analysis on selected areas
☐ Imaging analysis of the whole surface
☐ Taking off samples from selected points
☐ Applying in situ only one, no invasive technique
☐ Applying in situ a combination of no invasive techniques
☐ Observation of the surface with the microscope and acquisition of photos of some areas
☐ 3D scanning and virtual reconstruction
☐ Others.....

PA.b- Which of the following requirements are important for investigation of paintings? (select no more than 3 options)

☐ A careful choice of representative sampling/measurements points/areas
☐ Ability of positioning the acquisition probes of punctual techniques on selected areas/points and repeatability of positioning in time
☐ Ability of performing several analytical techniques on the same area/point in order to achieve complementary information
☐ Ability of mapping the results of punctual techniques on a coarse 3D global representation of the artwork
☐ Ability of detecting surface changes induced by ageing or by treatments through the check of the visual appearance of selected areas (texture, color, gloss, roughness, microdistortion of the reflected light)
☐ Ability of detecting material changes induced by ageing or by treatments through the check of the chemical and physical features of selected areas (thickness of layers, composition)
☐ Ability of imaging the whole surface with techniques of different penetration depth (IR and ultrasound)
☐ Ability to perform analysis in situ, without moving the painting from its usual exhibition place
☐ No invasiveness of the techniques used

☐ Others.....

Digitalization, simulation and 3D printing of artworks DS

The Scan4Reco project aims at developing a software to help process the data acquired, classify the artwork state, and simulate the change of artworks under certain conditions or because of conservation treatments. Further project' aims are to improve 3D printing and the planning of a Virtual Museum for the display of digital reproductions.

DS.a- How can a software help people involved in collection care and conservation? (select no more than 3 options)

☐ By discriminating superficial and sub-superficial materials

☐ By discriminating superficial and sub-superficial differences over time as a consequence of both aging and interaction with pollutants

☐ By comparing superficial differences induced by restoration procedures

☐ By comparing superficial changes induced by the application of a varnish

☐ By predicting the evolution of the object conditions, given a specific display environment

☐ By reconstructing the original appearance of the object

☐ By extracting early warning parameters in order to plan maintenance interventions

☐ By predicting the visual appearance of the whole surface after a conservation treatment

☐ Others.....

DS.b - The following questions should be answered with numbers: [1] very important, [2] important [3] nice to have [4] not important

☐ How important is an accurate reproduction of the object's 3D geometry (could also be the relief created by brush strokes in paintings)

☐ How important is the reproduction of the overall object's material appearance or appearance attributes (color, translucency, gloss)?

☐ How important is the accurate reproduction of color?

☐ How important is the accurate reproduction of gloss?

☐ How important is the accurate reproduction of translucency?

☐ Wood and other materials change appearance depending on illuminating/viewing geometry. How important is the accurate reproduction of this kind of directional reflectance?

☐ Multimaterial 3D printing allows using fully transparent printing material. This can be used for visualizing hidden parts of the objects beneath its surface while

preserving the overall object geometry (using the transparent material). This can be also visualized on a display. How important is such visualization by a print?

DS.c -What replicas of artwork by accurate 3D printing can be useful for? (select no more than 3 options)

- ☐ To be sent to exhibits and shows in place of the actual artwork
- ☐ To be put in places not matching preservation requirements (harsh environment)
- ☐ To reconstruct the original context where the artwork originally was (example facades, altars, fountains)
- ☐ To reconstruct missing parts
- ☐ To fill lacunas of preparation and pictorial layers in a new way
- ☐ To show the public the appearance the surface had before alteration and degradation
- ☐ To show the public the visual appearance of the surface with its original pictorial layer or partina (with no overlayer)
- ☐ To show the public a cross-section with the stratigraphy of the artwork
- ☐ Others…….

DS.d- Please answer the following questions using one or multiple sentences:

Which objects would you like to print (sculptures, paintings, etc..)?

For which purposes you would like to use 3D printing (visualization, supporting conservation, archiving, merchandizing, etc.)?

How big are the objects you would print? (range in millimeters, centimeters, meters)

What is the sufficient 3D printing resolution? Which level of details would you like to reproduce by 3D printing (micrometers, millimeters, centimeter)?

Which materials are the objects you would like to reproduce by 3D printing made of (metallic, wood, stone, plastics, etc.)?

Other requirements OR

The Scan4Reco project aims at developing a computer-based information system -Decision Support System (DSS) - that is able to process all relevant data on an artwork and combine them as to extract a list of ranked suggestions for supporting the unavoidable observations and evaluation made by the scholars.

OR.a- What procedure do you use for making decisions on conservation treatments (cleaning, protection)?

☐ Test areas on the object to be restored and comparison by visual observation
☐ Test areas on the object to be restored and comparison by scientific examination
☐ Literature survey on similar cases
☐ Guidelines and recommendations
☐ Others.....

OR.b- Which factors do you consider as most important when you choose a cleaning procedure on paintings or on metal objects?

☐ The visual appearance of the surface after the cleaning
☐ The roughness of the surface at a micrometer level after the cleaning
☐ The remnants of the layer to be removed which are left after the cleaning
☐ The color and glossy change after the cleaning
☐ Others……

OR.c- Which factors do you consider as most important when you choose a coating to lay on paintings or on metal objects?

☐ The visual appearance of the surface after the application of the coating
☐ The change of roughness of the surface at a micrometer level after the application of the coating
☐ The time evolution of the coating in the display environment in terms of appearance
☐ The behaviour of the coating over time in terms of protection performances
☐ The color and glossy change after the application of the coating
☐ The reversibility of the coating over time
☐ Others……

Thank you for your cooperation!