3D Digitisation of Icons of European Architectural and Archaeological Heritage

3D ICONS

D4.3: Final Report on Post-processing

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Contents

Executive Summary

Deliverable 4.3 is a final presentation of all the aspects concerning the post-processing of the 3D digitisations that will be supplied to Europeana by the content providers. The report describes the completion of the geometrical and graphical phase of the 3D digitisation, with respect to the schedule and the fulfilment of the identified requirements, also including some problems that were met and the solutions adopted.

It provides a global overview (summarising and incorporating the outcomes of D4.1 – interim report) of the post-processing phase by analysing and classifying the most commonly used approaches and techniques for the elaboration and the refinement of 3D models. Finally, this report includes a discussion about some approaches for producing several final outputs starting from a 3D digitization according to different representation purposes as well as an explanation of the relation between the post-processing work and the metadata creation.

Activities concerning WP 4 started at month 12 and ended at month 30 of the project. As presented in section 2.3 at the month 30 of the project (July 2014), the completed 3D digitisations (98,3% of the total planned) have been post-processed by producing **3230** 3D models ready to be converted in the final publication formats (WP5).

D4.3 Final report on post-processing

1. Introduction

1.2 Post-processing in the 3D-icons project

The 3D-ICONS project will provide to Europeana an important collection of reality-based 3D models (detailed and accurate geometric representations) for further uses such as documentation, digital inventories, cultural dissemination, etc. This report concerns the activities carried out within the framework of the task 4.1 :

- The refinement of the 3D digitization produced in WP3 (Digitization), including geometric reconstruction, visual enrichment and model structuring;
- The making of all necessary graphical and content refinement improvements of the model and the other data provided;
- The creation of some complementary 2D media (derived from the 3D model) such as video tours, panoramic images, etc. for enriching the documentation of the monument and its details.

After a brief introduction, this final report presents a general overview of the post-processing activities (see section 2) discussing the actions undertaken in order to coordinate the implementation as well as the monitoring. Section 3 focuses on a discussion about technical and methodological issues (lessons learned) about the most used post-processing approaches, while section 4 explain how the produced data sets (including 3D digitations, post-processed 3D models and complementary 2D media) are used for elaborating a collection of digital assets documenting an heritage asset according to several criteria (representation purposes, temporal states, object scales, etc..) ready to be converted in the final publication formats (WP5). Finally, section 5 discusses the relationship between the post-processing workflow and the metadata creation.

1.3 What is 3D post-processing?

First of all, it is necessary to start the discussion with an explanation of what is meant by 3D post-processing. To provide a simple and clear example, one can first refer to the post-processing of 2D images (see Figure 1 on the left hand side below). This process is generally well known in the field of digitisation and generally involves applying some filters to enhance the image or change its resolution. Unlike the 2D post-processing, 3D post-processing (see Figure 1 on the right) is a much more complex process consisting of several processing steps concerning the direct improvement of the acquired data (by laser scanning, photogrammetry, etc. ..) as well as its transformation into visually enriched (and in some cases semantically structured) geometric representations. As can be understood in section 4, post-processing also allows the elaboration of multiple 3D models starting from the gathered data according to various representations purposes, levels of resolution and description strategies (segmentation of elements in parts and sub-parts). The results of the post-processing phase are 3D geometric representations accompanied by complementary 2D media, which are the digital assets ready to be converted (or embedded) into the final web publishing formats (WP5).

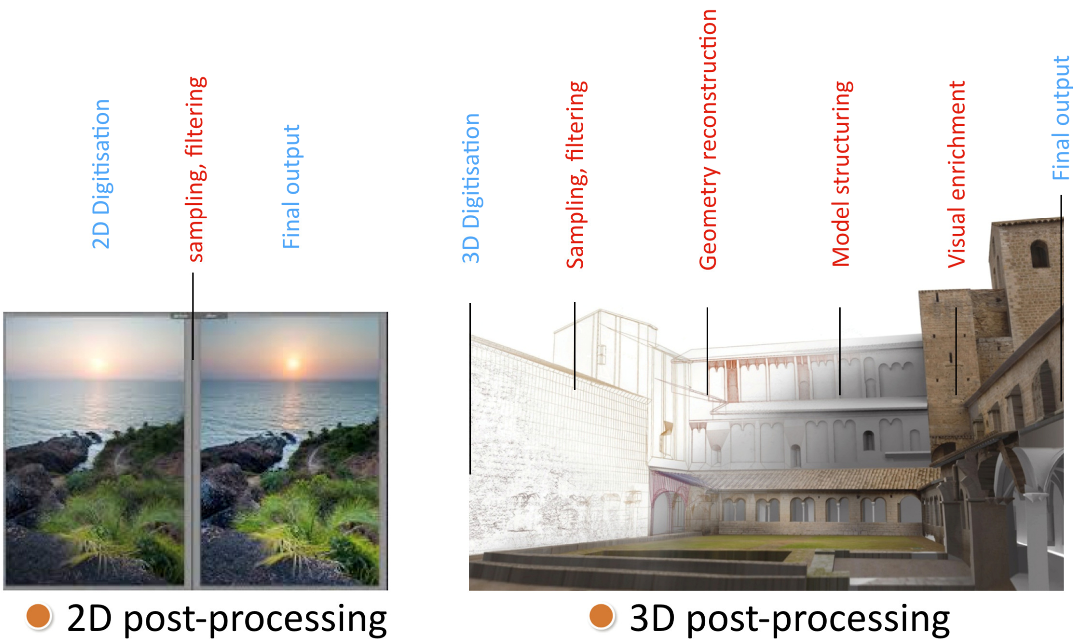


Figure 1. Difference between 2D and 3D post-processing

2. General overview of the post-processing activities carried out within the 3D-ICONS project

2.1 Problems encountered and actions undertaken

Initial internal discussions focused on finding a good way for articulating the post-processing activities within the entire pipeline. This revealed an important overlap between the two work packages concerning the digitization implementation: WP3 (data acquisition) and WP4 (post-processing). In fact, several processing activities can be considered to be part of the data acquisition (WP3) as well as part of the post-processing (WP4) according to the used digitisation and processing approach. In some cases, the 3D digitization solutions (integrating hardware and software) merge the data acquisition (WP3), the geometric reconstruction (WP3/4) and the visual enrichment (WP4) into a unique automatic process; in other cases, the data acquisition (WP3) is strongly independent from the 3D modelling and structuring strategy (WP3/WP4), and so on.

For example, concerning the 3D modelling carried out by automatic geometry processing techniques (e.g. the 3D digitisation of a sculpture), the post-processing is affected by factors hindering 3D data collection such as transparency, reflectance, poor light conditions, accessibility of the object and its position, geometric complexity of the object etc. In this case, the post-processing consists of applying functions such as filling holes and gaps, correction of corrupted or duplicated sides and vertices, refinement and cleaning anomalies caused by defects of light conditions and texturing.

But a historic building or an archaeological site is generally composed by the articulation of elements at various scales and levels of geometric complexity. As a consequence, the 3D digitisation requires the integration of various 3D digitisation and modelling techniques. This specific context makes it difficult to really segment some of the more complex pipelines into well-identified processing steps. In fact, the overall pipeline generally depends on the main purpose of the 3D digitisation, the specific strategy to produce the general model, as well as the final visual and geometric result to be achieved.

In addition, some content providers in the project have significant experience with 3D digitization and representation of heritage artefacts, sometime coupled with an in-depth knowledge of tools, methods and approaches, which constitute the results of their scientific activity. Furthermore, beyond the use of common and commercial solutions for handling 3D representations in various formats, within the context of this project, and in order to obtain excellent results in terms of geometric and visual accuracy, some project partners are experimenting with the integration of several tools and emerging technologies into more complex 3D reconstruction approaches.

Due to the WP3/WP4 overlap problem as well as the high heterogeneity of the developed approaches (sometime resulting from a strong integration of technical and methodological aspects), first of all we carried out the study of a common basis to be used for classifying the different operating modes, as well the data structures and the file formats used for handling geometrical and visual content (see section 3). This classification has a twofold objective: on one hand the aim of harmonizing the production of 3D models within the framework of the project (as well as the description of the processing steps during the technical metadata creation phase); on the other hand, the need to identify common refinement pipelines according to the final publication formats (WP5).

Another important action undertaken concerns the definition of a strategy for considering the post-processing phase as a key moment for producing 3D models according to various description purposes. The technical review (month 24) recommended identifying a set of clear guidelines for the identification of individual 3D objects to be delivered to Europeana. From a technical point of view, this issue concerns the post-processing phase and contributes to the critical mass of delivered objects (see table 1 the next section). A set of criteria have been identified in order to isolate some individual (and interesting) assets from the surrounding structure (e.g. architectural elements, sculpted details, furnishing, etc…) as well as to produce several representations of the same heritage assets according to specific purposes (see section 4).

2.2 Progress on post-processing activities

Activities concerning the WP4 started at the month 12 and ended at the month 30 of the project. At the end of this WP (july 2014), the completed 3D digitisations (98,3% of the total planned) have been post-processed by producing **3230** 3D models ready to be converted in the final publication formats (WP5). The following table shows in the first column the number of planned 3D acquisitions, in the second one, the number of objects for which partners already achieved the 3D digitisation (WP3) and in the third one, the final number of 3D digital assets resulting from the post-processing (WP4).

	Planned 3D Acquisitions	WP3 Completion of Digitization	WP4 Completion of Modelling
ARCHEOTRANSFERT	207	207	140
CETI	18	18	48
CISA	128	117	98
CMC	20	20	21

CNR-ISTI	210	210	157
CNR-ITABC	155	138	109
CYI-STARC	71	70	70
DISC	117	117	53
FBK	57	57	64
KMKG	455	455	693
MAP-CNRS	349	331	521
MNIR	80	80	61
POLIMI	531	531	743
UJA-CAAI	586	586	402
VisDim	50	50	50
Total	**3034**	**2987**	**3230**

Table 1. Progress of the 3D digitisation (acquisition and post-processing) activities carried out by the partners at the month 30 (July 2014).

One can consider this progress good, because the post processing activities concern the complex phase of the elaboration of final 3D representations starting from the gathered data. In fact, as explained in section 3, according to the morphological complexity of the artefact, different geometric reconstruction and visual enrichment techniques are often integrated. In the case of complex architectural buildings, even if the digitization phase is often carried out in an automatic way (e.g. 3D laser scanning) an important activity of interactive modelling and structuring (time expensive) is required.

By analysing the values reported into this table, one can notice an increment of the number of 3D models from WP3 to WP4. In fact, the **2987** completed 3D digitisations (results of the 3D scanning) have been used to produce **3230** digital assets.

This "increment" is driven by a set of criteria presented in section 4 and depends on the nature of the heritage asset and on the post-processing activities which include several possible techniques for the 3D geometric reconstruction, the visual enrichment, the model structuring (and in some case the model segmentation into individual elements), as well as the production of alternative representations (e.g. hypothetical states, levels of details, etc…). The multiplication of the 3D models is carried out thanks to contribution of the scientific advising (specialists or experts that are in all institutions involved in 3D-ICONS). Furthermore, some models have been multiplied, as it wasn't possible to publish them in high resolution given the morphological complexity of the heritage asset.

For example, **KMKG** produced **693 3D models** starting from **455 digitisations**, **MAP-CNRS 521 3D models** from **331 digitisations** and **POLIMI 743 3D models** starting from **531 digitisations**. This shows a positive trend illustrating that the overall number of the ingested models will increase in the next months, according to the final conversion towards the publication formats (WP5).

3. Study of the methodological approaches for post-processing

This section incorporate the results presented in the D4.1 - interim report (see section 3.1 to 3.2), then presents the results of a survey (see section 3.3) carried out within the partners of the project in order to provide some statistics concerning the most used techniques and formats for the post-processing phase. The study of these methodological approaches, accompanied by an in-depth analysis of four case studies is then used as starting point for identifying two typical post-processing pipelines determining the final outputs to be converted into 3D interactive media (within the framework of the WP5 – publication).

3.1 Introduction

From a purely technological standpoint, during the generation of the 3D representation of an artefact, the geometrical precision, the detailed representation of visual aspects, the 3D real-time visualization are fundamental aspects. But, beyond the application of a technical process, whether simple or integrated, the methodological dimensions plays an important role in identifying the objectives of 3D representation that can be achieved starting from a 3D-digitization. Indeed, in several cases, the type of representation desired for the communication purpose (or required for the analysis needs) determines the data processing and post-processing strategy. In fact, the elaboration of 3D models of complex heritage buildings in their current state, as well as the reconstruction of their hypothetical past states, requires the definition of specific pipelines integrating surveying tools, geometric modelling techniques and (in some cases) an overall model structuring strategy.

Four main approaches are representative of the diffuse practices among the 3D-ICONS partners working on the digital documentation and visualization of heritage artefacts Firstly, some approaches are inclined to **represent the geometric accuracy of 3D models**: these are mainly based on methods of automatic meshing starting from a 3D laser scanning acquisition. Secondly, other approaches are based on **morphological descriptions** that are specific to particular kinds of analysis (e.g. temporal transformations, architectural composition, etc.); they are characterized by data acquisition and data processing strategies consistent with specific representation goals. Thirdly, some techniques focus on **reproducing the visual appearance** of the surfaces forming the object, by taking into account photographic information. Finally, other approaches concentrate on the **simultaneous representation of multiple factors at multiple scales**: for this goal, they use different technical procedures in a complementary way.

In order to define a set of common elements of an overall methodology (taking into account the heterogeneity of the 3D reconstruction approaches used by the project content providers), we firstly analysed several 3D reconstruction projects carried by content provides in order to produce a classification of the main procedures. This first analysis, carried out by studying and comparing a range of technical solutions, allowed the structure of a set of typical 3D reconstruction pipelines (from the 3D surveying on-site to the final 3D model used for various application contexts) to be identified.

In the following section, post-processing issues and solutions provided by partners are used as examples for each of the post-processing steps where applicable.

3.2 Classification of elementary "processing steps"

For the purpose of identifying a set of elementary "processing steps" which can be combined in several ways in order to compose 3D reconstruction pipelines, this analysis takes into account the:

- Deployed digitization tools (3D scanners, digital cameras, etc.);
- Employed acquisition, geometric modelling and visual enrichment techniques;
- Source and final data formats.

Five general post-processing aspects (detailed in the following sections) have been identified: geometric reconstruction, visual enrichment, model structuring, hypothetical reconstruction and complementary 3D media (derived from the 3D model). This work is mainly based on the experiences of CNRS-MAP, CMC and UJA-CAAI as well as on several inputs coming from the WP2 (CNR-ISTI) and WP3 (POLIMI, FBK) leaders.

3.2.1 Geometric reconstruction

The geometric reconstruction is the essential processing step for the elaboration of a 3D representation of an artefact (starting from the results of a digitization campaign). The choice of the relevant technique (see Figure 2) for this step is generally based on the evaluation of the morphological complexity of the object, its scale, as well as the purpose of the final 3D representation (e.g. graphic documentation, metric analysis, dissemination, etc.).

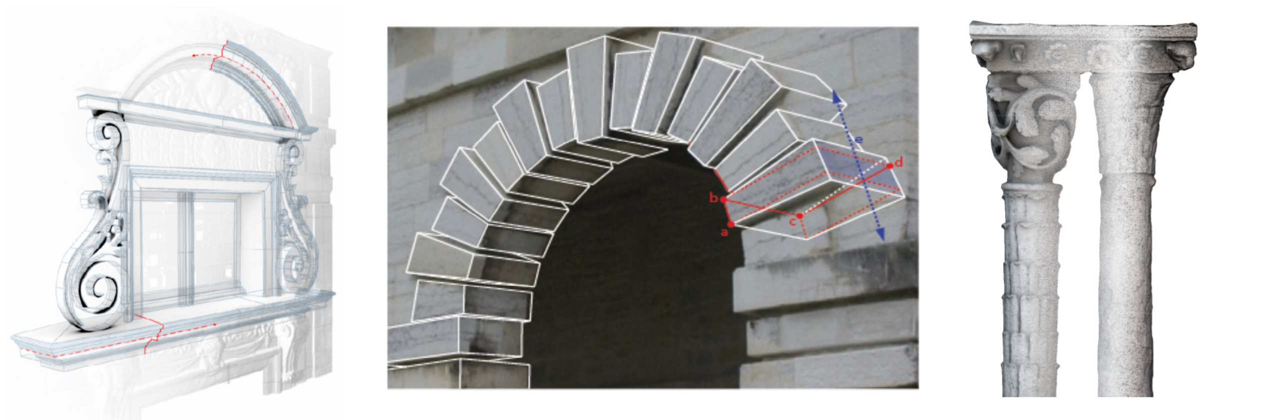


Figure 2. Examples of geometric reconstruction techniques (CNRS-MAP)

A simple criterion for choosing (and evaluating) a relevant 3D reconstruction technique is the degree of consistency of the 3D model with the real object. The list of techniques below is ordered from those, which ensure high geometric consistency with the real object to the techniques that introduce increasing levels of approximations:

- Automatic meshing from a dense 3D point cloud;
- Interactive or semi-automatic reconstruction based on relevant profiles;
- Interactive or semi-automatic reconstruction based on primitives adjustment;
- Interactive reconstruction based on technical iconography (plans, cross-sections and elevations);
- Interactive reconstruction based on artistic iconography (sketches, paintings, etc.)

3.2.2 Visual enrichment

With regard to the visual enhancement of the geometric 3D reconstructions, several computer graphics techniques were systematically examined in order to assess their degree of relevance in the specific context of the digitization of heritage artefacts. As this project aims to provide detailed and geometrically accurate 3D digitisations of heritage artefacts, our analysis primarily focuses on techniques that provide the simulation of visual characteristics in geometric consistency with the real object (see Figure 3). Other techniques, mainly used for cultural disseminations purposes, are taken into account.

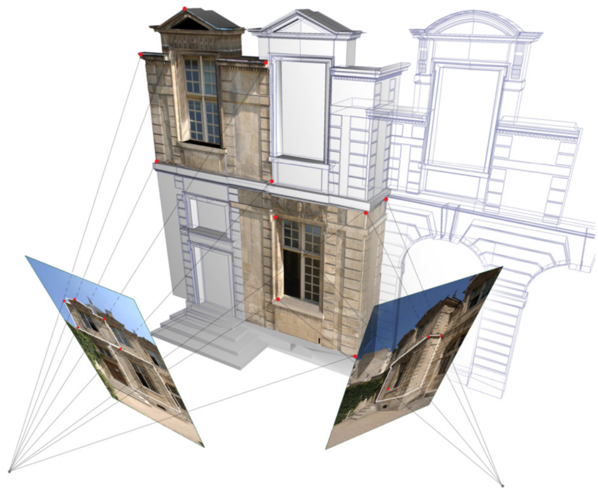


Figure 3. Example of visual enrichment based on the projection of textures starting from photographs finely oriented on the 3D model (CNRS-MAP)

The list of visual enrichment techniques below are ordered from those that ensure a strong geometric consistency with the real object to the techniques that introduce increasing approximations:

- Texture extraction and projection starting from photographs finely oriented on the 3D model (e.g. image-based modelling, photogrammetry);
- Texturing by photographic samples of the real materials of the artefact;
- Texturing by generic shaders.

Concerning the archiving of the results of the visual enrichment processes (textures, shaders, colours, etc.), it's very difficult to identify some general approaches because, in most cases, these aspects are directly related to the 3D modelling and rendering software used, and often directly embedded (in proprietary format) into the general 3D scene.

- Storing textures at different levels of resolution;
- Storing the source images used to generate textures;
- Using standard formats for image-based textures;
- Using standard descriptions of shaders.

3.2.3 Model structuring

Depending on the scale and on the morphological complexity, a geometric 3D reconstruction of an architectural object or an archaeological site generally leads to the representation of a single (and complex) geometric mesh or a collection of geometric entities organized according to several criteria. The model structuring strategy (see Figure 4) is generally carried out with the aim of harmonising the hierarchical relations, which can express the architectural composition of a building (e.g. relations between entities and layouts) and can also be used as a guideline for structuring the related metadata. In some cases, it could be important to identify a scientific advisor ensuring the consistency of the chosen segmentation (e.g. temporal layers) and nomenclature (e.g. specialised vocabulary).

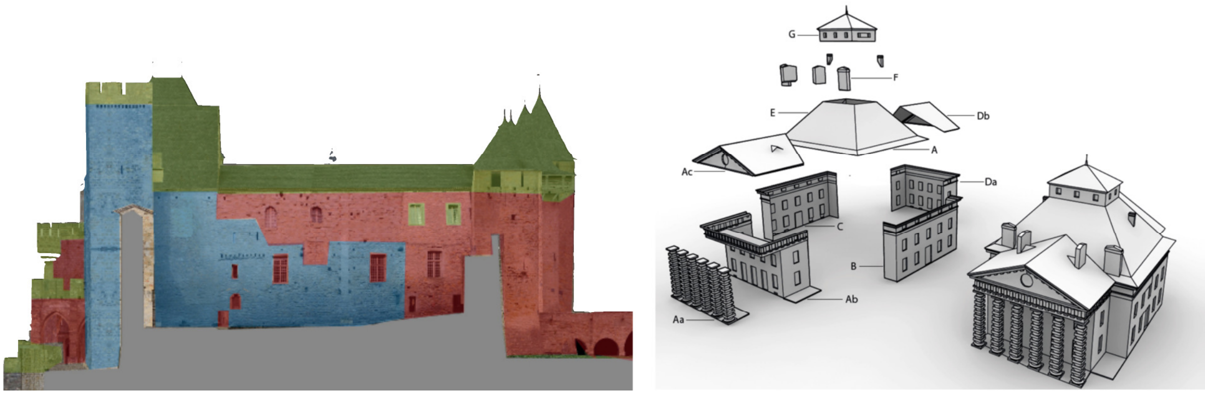


Figure 4. Example of 3D model structuring (CNRS-MAP) : on the left, according to temporal states; on the right, according to a morphological segmentation (architectural units).

According to the technique used and to the general purpose of the 3D representation, the results of a geometric reconstruction can be structured in four ways:

- Single unstructured entity (e.g. dense point clouds, or detailed mesh);
- Decomposed in elementary entities (e.g. 3D models composed by few parts);
- Decomposed in elementary entities hierarchically organized (e.g. 3D models decomposed in several parts for expressing the architectural layouts);
- Decomposed in entities organized in classes (e.g. 3D models decomposed in several parts for expressing the classification of materials, temporal states, etc.).

According to the chosen model structuring strategy, the final dataset structure (including geometry and visual enrichment) can be composed in several ways.

3D geometry:

- Single structured 3D file (with one level of detail);
- Multiple independent 3D files (with one level of detail);
- Multiple independent 3D files (with multiple level of detail);
- Hierarchical partition-based multi-resolution data structure, in a single file.

Textures:

- Embedded into the 3D geometry file;
- Stored as external 2D files.

3.2.4 Hypothetical reconstruction

The hypothetical reconstruction of the past state of an architectural object or archaeological site is an issue primarily related to field of historical studies. Nevertheless, some specific technical and methodological issues with 3D graphical representation of disappeared (or partially disappeared) heritage buildings are often integrated in 3D reconstruction approaches. While primarily related to the analysis of iconographic sources and historical knowledge, the methodological approaches for the elaboration of hypothetical reconstructions (see Figure 5) can be based on the integration of metric representations (2D or 3D) of existing parts of the object, as well as on the reconstruction of the objects shapes starting from non-metric graphic descriptions of the artefact.

According to the informative degree of the iconography available as a source, the elaboration of the 3D representation of the hypothetical state of an artefact, may mainly be carried out based upon :

- the 3D acquisition of existing (or existed) parts;
- previous 2D surveys of existing (or existed) parts;
- non-metric iconographic sources of the studied artefact;
- iconographic sources (metric and / or non-metric) related to similar artefacts;

These methods (which can also be used in a complementary way) do not necessarily determine the procedures, but emphasize the importance of the scientific dimension, the intellectual rigor and transparency in the development of a hypothetical reconstruction. In this sense, in order to include the 3D reconstruction of hypothetical states of an artefact into an effective context of production of historical knowledge, the following recommendations should be taken into account:

- Identify the scientific advisor(s) which can guide and validate the 3D model during its elaboration;
- Save information about iconographic sources and bibliographical references and used in the elaboration of the 3D model;
- Identify and save information indicating the degree of uncertainty (information gaps, doubts, etc.).

Figure 5. Example of 3D hypothetical reconstruction of a past state (CNRS-MAP)

3.2.5 Complementary 2D media (derived from the 3D model)

During the elaboration of the 3D representation of a heritage artefact, complementary 2D are produced starting from the 3D model. This 2D media can be produced in different ways, depending on the type of 3D source (point cloud, geometric model, visually-enriched 3D model), as well as on the final visualization type (static, dynamic, interactive). As those 2D documentary media are directly derived from the 3D model, with the aim of anticipating the metadata creation, it could be important to underline the relationships which can be established between images, videos, etc. and the 3D model. 2D complementary media can be produced starting from (and still remain linked to) the 3D general model of the entire architectural or archaeological artefact or to entities or sub-entities of the 3D general model (see section 4).

3.3 Case studies on post-processing

Starting from the results of the aforementioned classification, a set of typical 3D post-processing pipelines has been identified by basing on several aspects. First, the common articulation of several elementary processing steps into a relevant process. Second, the evaluation of the relevance of each elementary processing steps (as well as the combination of some processing sequences) according to the object scale, its morphological complexity and its final representation format. The following sections illustrate some examples showing the relationship between the characters of the artefact (morphological complexity, scale, typology, etc.) and the chosen post-processing pipeline (composed by several elementary processing steps).

3.3.1 Cerveteri and Tarquinia Tombs (FBK)

A - GEOMETRIC RECONSTRUCTION
- Automatic meshing from a dense 3D point cloud

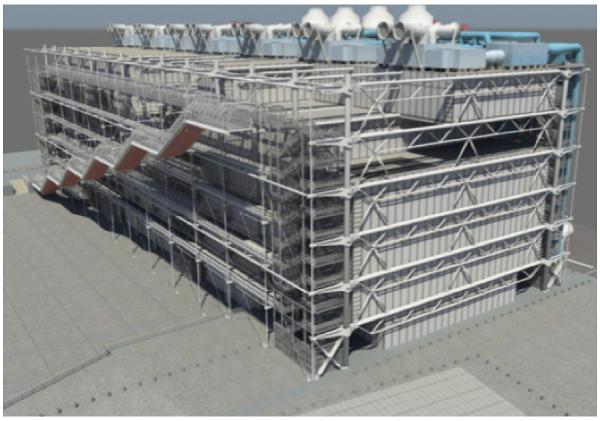
B - MODEL STRUCTURING
- Unstructured, single mesh

C - VISUAL ENRICHMENT
- Texture extraction and projection starting from photographs finely oriented on the 3D model (photogrammetry)

D - DATASET STRUCTURE (Geometry)
- Single 3D file with 1 level of detail

E - DATASET STRUCTURE (Textures)
- Sored as external 2D file

3.3.2 Centre Pompidou in Paris (CNRS)



A - GEOMETRIC RECONSTRUCTION
- Interactive and semi-automatic reconstruction based on relevant profiles
- Interactive reconstruction based on technical iconography (plans, cross-sections and elevations)

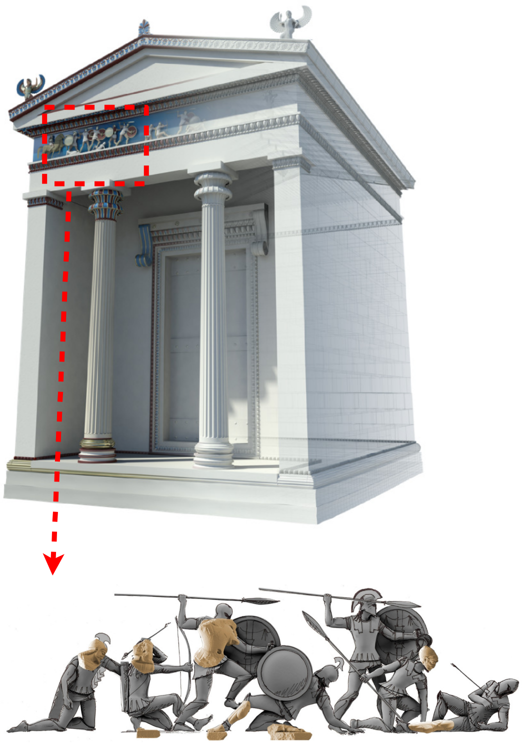
B - MODEL STRUCTURING
- Decomposed in elementary entities hierarchically organized (by following the architectural layout)
- Decomposed in entities organized in classes (materials)

C - VISUAL ENRICHMENT
- Texturing by photographic samples of the real materials of the artifact
- Texturing by generic shaders

D - DATASET STRUCTURE (Geometry)
- Multiple independent 3D files with multiple levels of details

E - DATASET STRUCTURE (Textures)
- Embedded into the 3D geometry file (generic shaders)
- External 2D images (external textures)

3.3.3 Treasury of Marseille in Delphi (CNRS)



A - GEOMETRIC RECONSTRUCTION
- Automatic meshing from a dense 3D point cloud *(sculpted elements)*
- Interactive *and* semi-automatic reconstruction based on relevant profiles *(existing architectural elements)*
- Interactive reconstruction based on *ancient* iconography (*hypothetical architectural elements*)

B - MODEL STRUCTURING
- Decomposed in elementary entities, partially hierarchically organized

C - VISUAL ENRICHMENT
- Texture extraction and projection starting from photographs finely oriented on the 3D model (Image-based-modeling)
- Texturing by generic shaders.

D - DATASET STRUCTURE (Geometry)
- Single 3D file structured with 1 level of detail

E - DATASET STRUCTURE (Textures)
- Embedded into the 3D geometry file
- Stored as external 2D files

F - HYPOTHETICAL RECONSTRUCTION
- Basing on the 3D acquisition of existing (or existed) parts;
- Basing on non-metric iconographic sources of the studied artifact;
- Basing on iconographic sources (metric and / or non-metric) related to similar artifacts;

G - SCIENTIFIC (Historic) ADVISING
- Scientific Committee (nomenclature, temporal states and hypothetical reconstruction)
- Bibliographic references (nomenclature and hypothetical reconstruction)

3.3.4 Roman archaeological finds (POLIMI)

A - GEOMETRIC RECONSTRUCTION
- Automatic meshing from a dense 3D point cloud

B - MODEL STRUCTURING
- Unstructured, single mesh

C - VISUAL ENRICHMENT
- Texture extraction and projection starting from photographs finely oriented on the 3D model (photogrammetry)

D - DATASET STRUCTURE (Geometry)
- Single 3D file structured with 1 level of detail

E - DATASET STRUCTURE (Textures)
- Stored as external 2D images

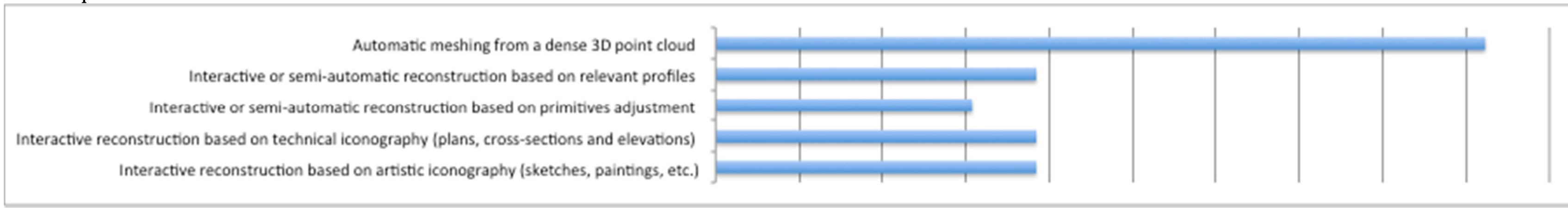
G - SCIENTIFIC (Historic) ADVISING
- Scientific Committee

3.4 Statistics on the employed approaches, techniques and file formats

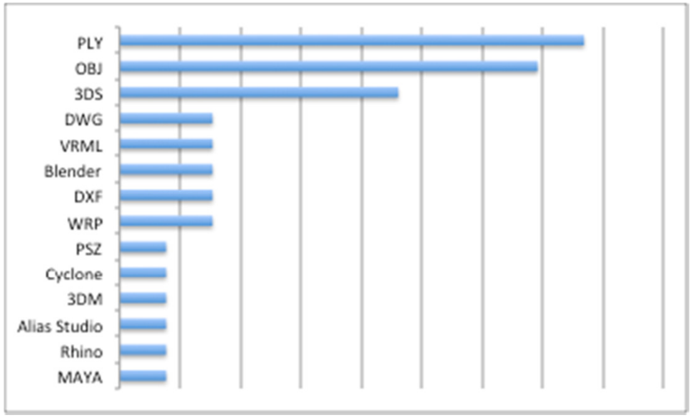
This section presents the result of a survey carried out within the partners of the project in order to identify the most used techniques and formats for the post-processing phase. The max values on the bar charts represent the most commonly used solutions.

3.4.1 Geometric reconstruction

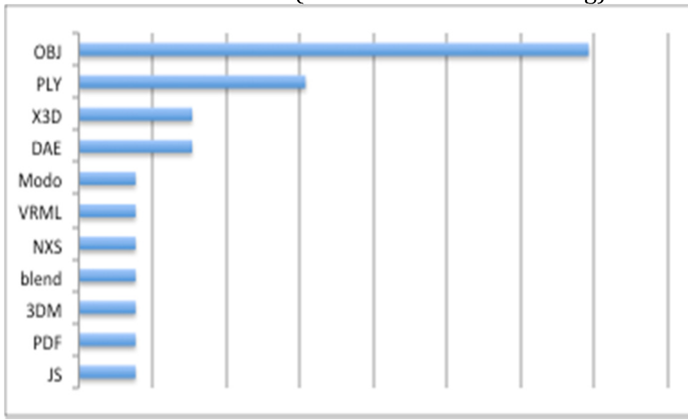
Techniques



Source 3D model format

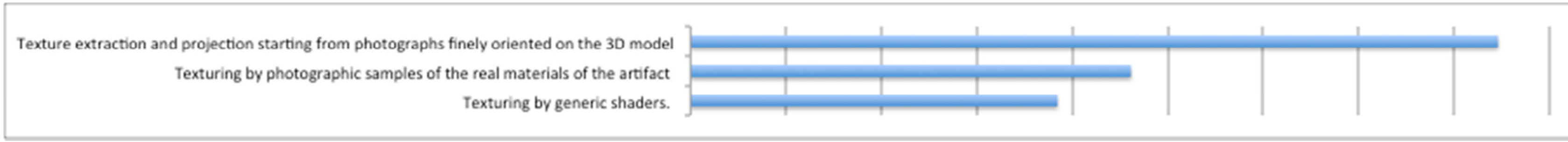


Final 3D model format (for 3D real-time rendering)

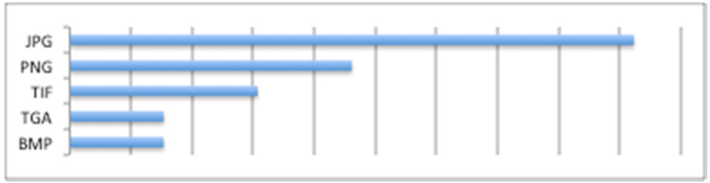


3.4.2 Visual enrichment

Techniques



Textures - Source 2D images format

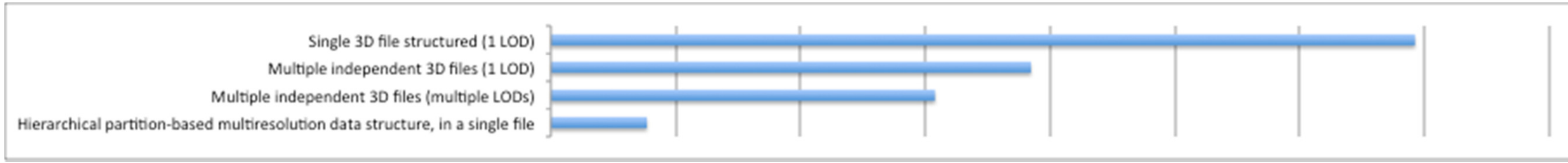


Textures - Final 2D Images format (for 3D real-time rendering)

3.4.3 Model structuring

Methodology

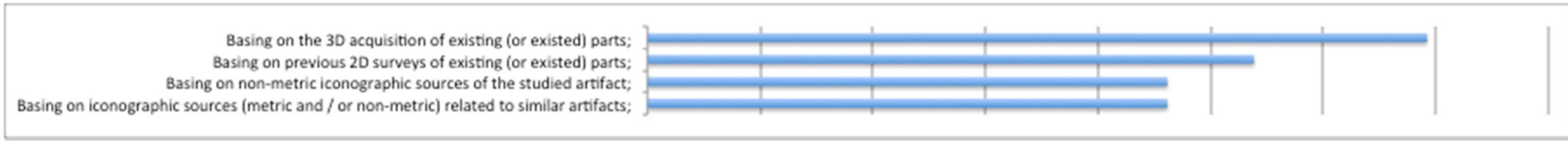
Dataset structure (Geometry)



Dataset structure (Shaders / Textures):

3.4.4 Hypothetical reconstruction

Methodology



Scientific (historic) advising

3.5 Typical post-processing pipelines.

According to the survey, two typical post-processing pipelines were identified determining the final outputs to be converted into 3D interactive media (see WP5 – publication). These two general pipelines depend on the specific nature of the initial 3D digitization, on the artefact morphology (historic building, sculpted detail, furnishing, archaeological find, etc..) as well as on the adopted model structuring (or segmentation) strategy (see next section).

PIPELINE _ TYPE 1

3D digitization and reconstruction: dense point cloud + regular mesh + texture mapping (or vertex colouring)
Processing: automatic processing + optimization
Model structuring: unstructured
Final 3D representation: the final model is generally managed in Meshlab, Geomagic, ...
This kind of 3D representation can be converted in PLY, OBJ formats in order to be exploited in WebGL-based 3D viewers, such us NEXUS (for dense meshes and point clouds) or Potree (only for dense point clouds). A low definition version of the 3D model can be embedded into a 3D pdf.

PIPELINE _ TYPE 2

3D digitization and reconstruction: Sparse point cloud (e.g. topographical surveying, technical drawings)+ structured geometry + texture mapping
Processing: semi-automatic and manual processing
Model structuring: generally structured (architectural layout, temporal states, etc.)
Final 3D representation: the final model is generally managed in 3Ds Max, Maya, Blender,…
This kind of 3D representation can be converted in Collada (.dae), OBJ, VRML formats in order to be interactively visualized by several 3D real-time engines (such as Unity, 3Dvia, etc..). A low definition version of the 3D model can be embedded into a 3D pdf.

The post-processing phase concerns essentially the elaboration of the 3D representation, at the appropriate level of geometric and visual accuracy, ready to be converted into the final publication format (WP5). Given the important geometric and visual detail obtained by the 3D digitization and post-processing techniques, the amount of polygons to be downloaded and visualised remain impressive, especially within the context of the web publishing. Without entering into issues concerning the publication (WP5), some techniques for drastically optimising/decimating the 3D models have been evaluated in order to produce very light 3D models embedding the geometric detail as a complementary texture (by using texture backing techniques). Figure 6 shows the results of this supplementary processing step applied to a column.

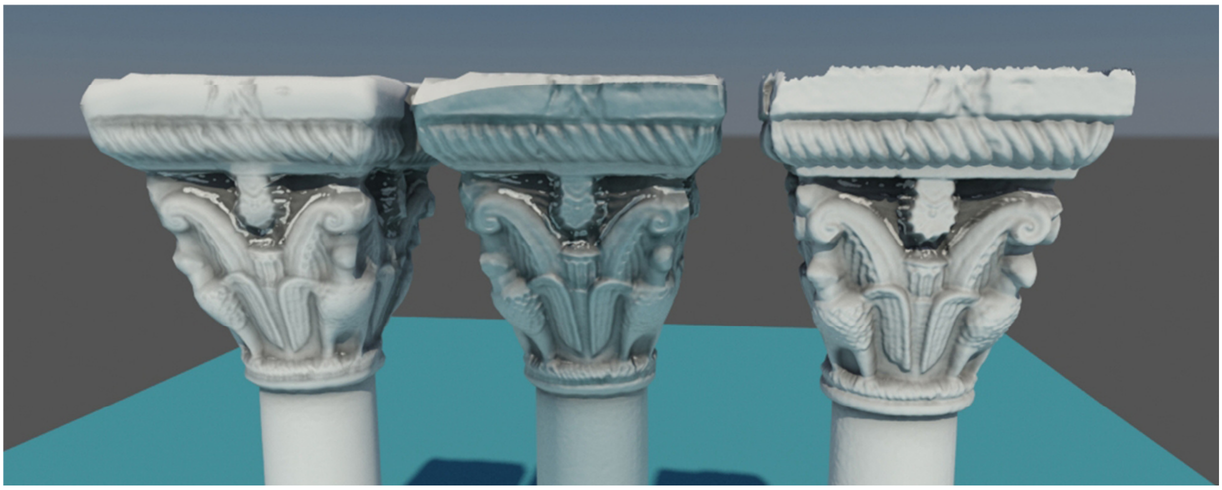


Figure 6. Results of a 3D model decimation/optimisation based on texture baking techniques: on the right, the original 3D model composed by 600.000 polygons (file size 140Mb), in the middle a 3D model (file size 2 Mb) composed by 5000 polygons and integrating an ambient occlusion + normal + bump maps; on the left a 3D model (file size 1 Mb) composed by 5000 polygons an integrating only an ambient occlusion map.

The results of this processing step can usually be interpreted by the recent WebGL-based 3D engines, as well as by several commercial 3D engines and some partners are currently testing the integration of these simplification techniques in their 3D modelling pipelines.

4. Producing multiple digital assets starting from a 3D digitisation

A historic building or an archaeological site is a very complex object requiring a 3D digitisation strategy according to its morphological, historical and semantic complexity. Then the post-processing of the acquired 3D data can be considered as a key for elaborating multiple digital assets according to specific purposes (education, preservation, dissemination, etc.). In this case, the semantic description of a complex artefact (e.g. by decomposing an historic building into a set of architectural units) the can be used for isolating several digital assets from a general structure. For example, a pillar in an architectural ensemble can be presented as one individual object given the particular interest of its sculpted iconography or the richness of its details. In this case, in order to provide a detailed 3D representation (also according to the limitations of a 3D real-time web visualisation in terms of number of polygons), it should be isolated from the surrounding structure and presented as an individual digital asset with its own metadata.

4.1 Criteria for multiplying the digital assets starting from a 3D digitisation campaign

Accordingly to the recommendations formulated by the reviewers in the 2nd year meeting, we defined a set of criteria for the identification of individual 3D digital assets.

- Breaking into different parts (e.g. pillar in an architectural ensemble, cloister-gallery in a monastery, etc.) is possible when the model (or models) of the details (or single parts of the monument) is (are) relevant from an artistic, architectural, archaeological perspective.
- Providing different models of the same object is possible when :
    - the object itself and alternative hypothesis on its virtual reconstruction;
    - different chronologies or phases;
    - the existing object (e.g. statues, small findings) before and after the restoration (this is a case quite frequent, for statutes, vases that are showed in the museums only after the restoration. One can remove parts and, if you believe necessary, you could add virtually part(s) to complete the object. One can also change the texture (e.g. images for Etruscan tombs with painted-walls) if one wants to deliver models concerning the state of the monument at the moment of its discovery and now: this could help potential users to compare the different state of conservation of the monument and to measure the decay in the course of time in terms of readability of the pictorial cycle, colour, etc.
- Carrying out the model by means of different technologies in the perspective to merge the different models: e.g. CAD model of a monument enriched with statues, frescos or other architectural details stored in another location (e.g. Museum, etc.), or architectural details, still in situ, of the CAD model acquired by laser scanner, SfM or other related technologies.
- Delivering models for different users:
    - High resolution models for researchers;
    - Intermediate resolution models for educational purposes;
    - Low resolution for general public.

4.2 A case study: the abbey of Saint-Michel de Cuxa

The following schemas illustrate the structure of a final dataset produced by the 3D digitisation and post-processing of the Abbey of Saint-Michel de Cuxa (south of France). Hundred of 3D models and thousands of 2D images, plus several complementary media such as renderings and videos, compose this dataset.

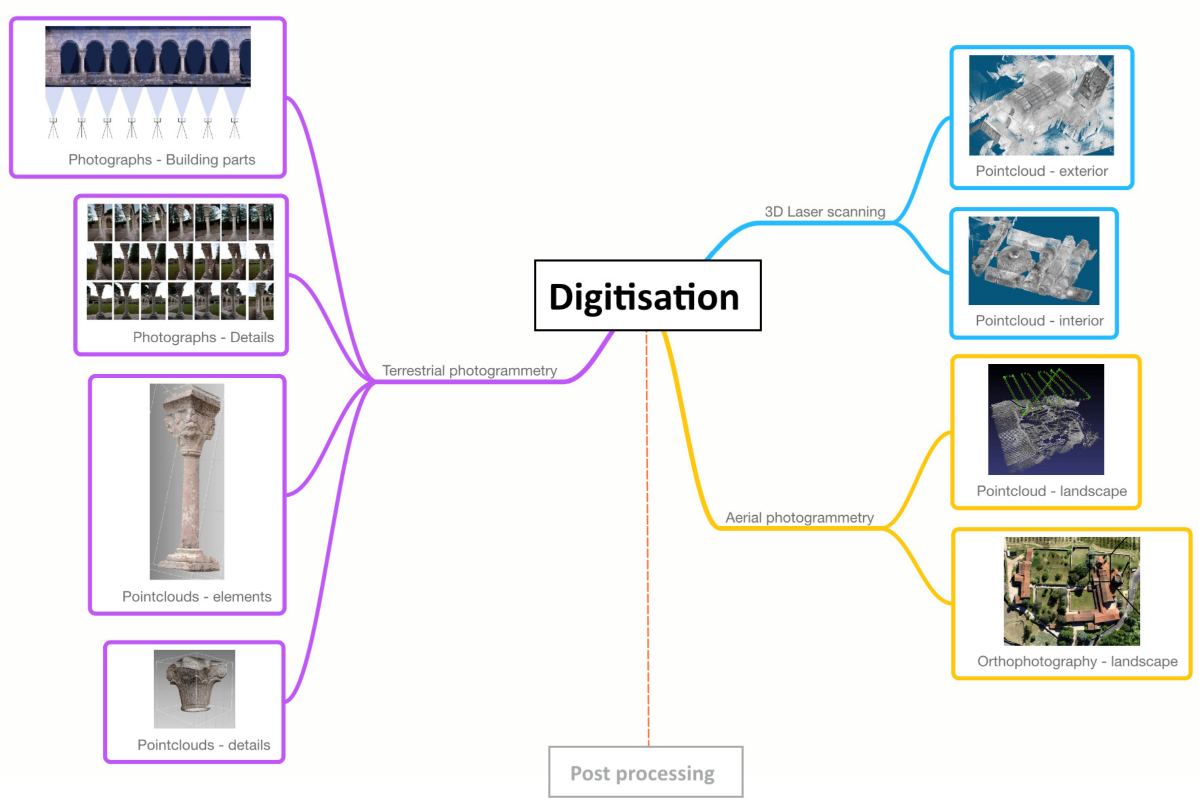


Figure 7. Dataset produced by the 3D digitisation phase. Abbey of Saint-Michel de Cuxa

The 3D digitisation of the Abbey of Saint-Michel de Cuxa is based on several surveying and 3D reconstruction techniques, coupled with a method for the semantic structuring of the 3D model. The first step consisted of a surveying campaign of the abbey, which has been led with a ToF 3D scanner. The resulting point clouds have been consequently merged into 41 millions coordinates connected each other in the same reference system (see Figure 7: blue frames). Besides the 3D laser scanning, a survey of more than 2000 photographs was conducted to collect basic information on the conservation status of surfaces and to render the visual appearance of volumes (see Figure 7: purple frames). On the basis of calibration, orientation, and multi-stereo matching techniques having been tested and developed in the MAP-CNRS laboratory, certain elements of details (such as the cloister columns) have been reconstructed with a high level of metric and visual resolution (see Figure 7: purple frames). With the goal of acquiring information on covers (roofs, etc.) and on the surrounding of the building, a remote-controlled drone (UAV) carrying a digital reflex camera was used. We acquired approximately 1000 photographs that have then been processed to produce an orthophotography of the abbey, by means of a mosaic of high definition rectified images (see Figure 7: yellow frames).

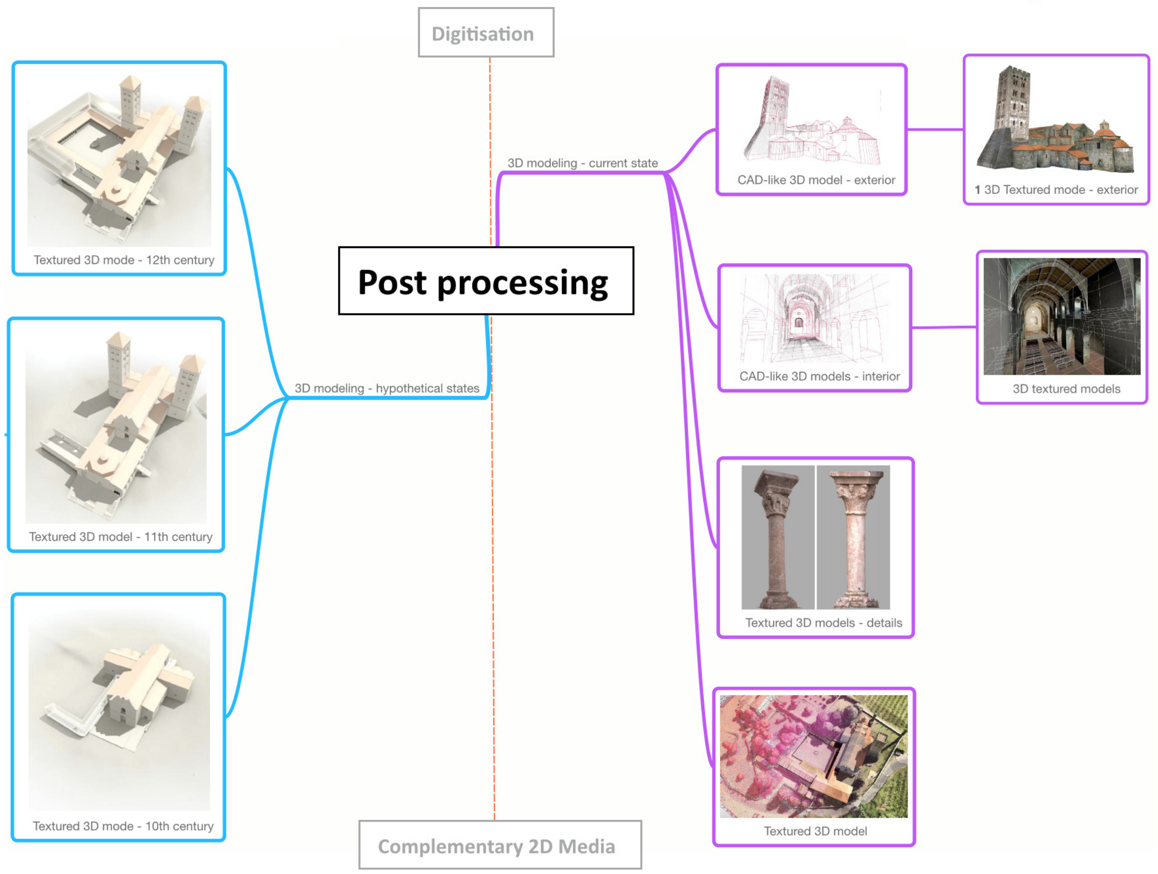


Figure 8. Dataset produced by the 3D post-processing phase. Abbey of Saint-Michel de Cuxa

3D point clouds acquired by laser scanner and oriented photographs (by photogrammetric techniques) have been used as a metric and visual support for the stage of 3D geometric reconstruction. This phase permitted us to represent the morphological complexity of the building through interactive and semiautomatic modelling procedures (see Figure 8:

purple frames on the top). In order to represent the richness of the sculpted items integrated to architectural elements, some procedures for automatic reconstruction from dense point clouds have been adopted. By exploiting the projective relation established between 3D point cloud and photographs, the created surfaces were then visually enriched by textures extraction (see Figure 8: purple frames on the bottom). This allowed representing the current state of the building with a good level of realism at several levels of detail. As a result of a calculation of dense matching, the orthophotography obtained from the UAV acquisition was also used for the generation of a digital terrain model that has been integrated to the 3D reconstruction of the building (see Figure 8: purple frames on the bottom). Starting from the gathered data on-site, an archaeological study on the previous states on the building has been carried out with a scientific committee. Three 3D models representing the cloister at different temporal states (10^{th}, 11^{th} and 12^{th} century) have been elaborated (see Figure 8: blue frames).

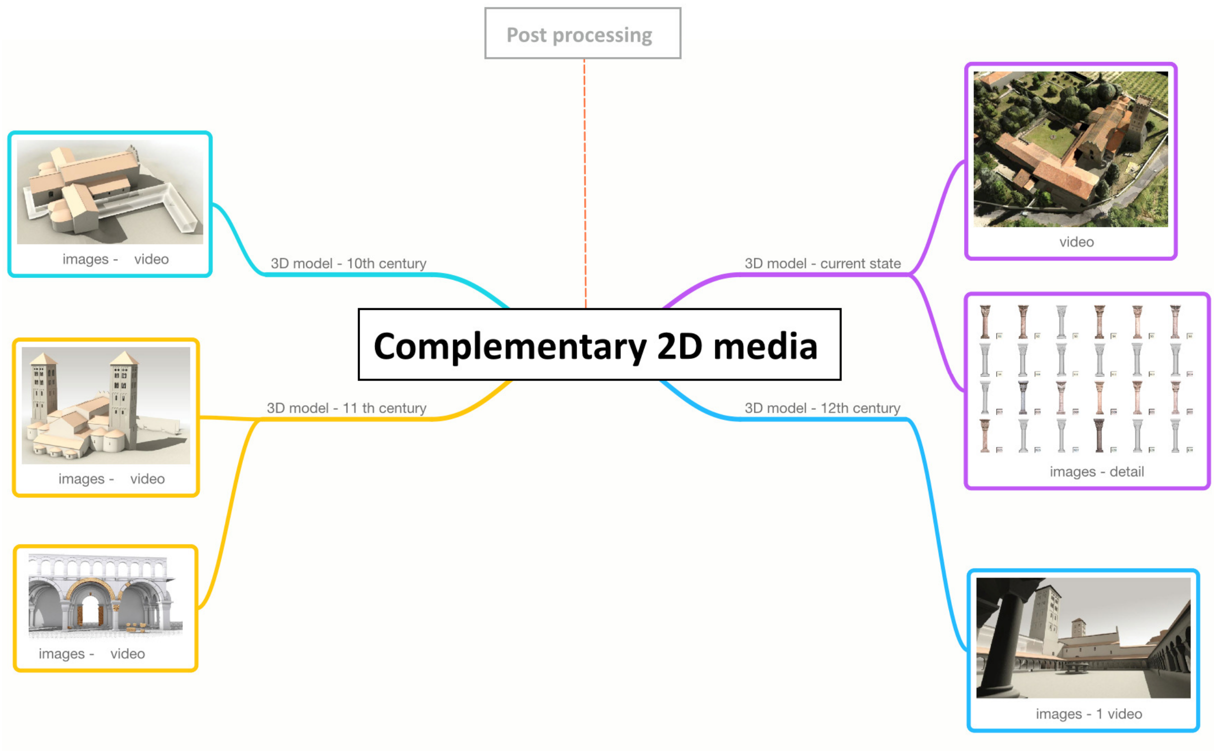
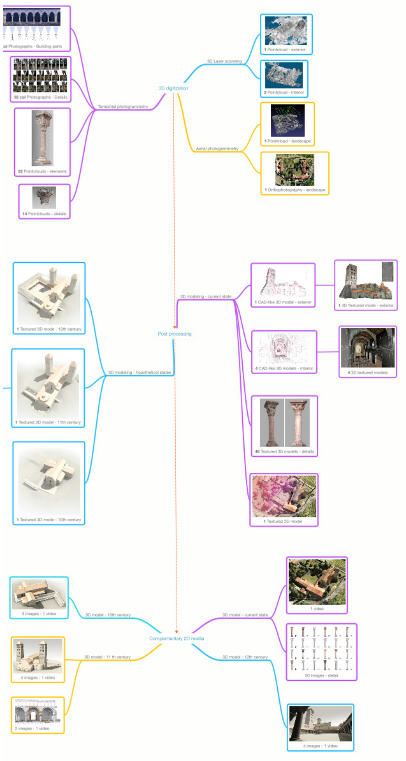


Figure 9. Complementary 2D media derived from the 3D model. Abbey of Saint-Michel de Cuxa

The combination of all these surveying techniques with complementary geometrical reconstruction has finally permitted us to create comprehensive representations of the abbey at different levels of details and at different (current and hypothetical) temporal states with a geometric/visual equilibrium suitable for real time 3D visualisation. In addition to the final 3D representations, several renderings and videos have been produced in order to present the results of the 3D digitization as well as of the historic study carried out during the project in a non-interactive (and easy-to-use) way (see Figure 9).



- **3D Digitisation**
  - Images : **75** collections (**+ 450** images) + **1** orthophotography
  - 3D models : **50** pointclouds
- **Post processing**
  - Current state :
    - **5** cad-like 3D models
    - **52** textured 3D models
  - Hypothetical states :
    - **4** textured 3D models
- **Complementary 2D media (derived from 3D models)**
  - **63** Images (rendering)
  - **5** Video animations

- -

- **Total**
  - **111** 3D Models
    - **50** pointclouds
    - **5** cad-like 3D models
    - **56** textured 3D models
  - **514** images
    - **75** images collections (+ 450 images)
    - **64** images (derived from the 3D model)

Figure 10. Entire dataset of the 3D digitisation of the Abbey of Saint-Michel de Cuxa

The entire 3D digitisation and post-processing workflow (see figure 10) produced **111 3D models**, **75 images collections** (acquired on-site), plus **64 images** and **5 videos** derived from the 3D models.

4.3 Multiple representations, multiple resolutions

As presented in the previous case study, from a purely technical point of view, the 3D digitation and post-processing stages allow structuring several representations of the same complex artefact. The difference among the multiple representations that can be obtained (by segmentation/structuring methods) from a 3D digitisation campaign relates to the quantity of geometrical information they can contain (also according to the 3D visualisation limitations – specially in the web publishing context). However, the study of a complex heritage artefact can use representation techniques exploiting various geometrical bases. It is, therefore, important to introduce a distinction between the concepts of resolution and representation: a representation results from the application of a description technique that allows visualising an individual object (or aspect) according to a geometrical base and to a resolution level (according to the observation/description requirements). Then, in order to provide a collection of digital assets for several potential users (researchers, educators, general public, etc.) each representation should reflect a specific purpose of potential users interested in studying or discovering heritage artefacts. The structure of the whole dataset produced by a 3D digitisation campaign can thus be exploited as a general repository able to deliver digital assets according to specific documentation and dissemination purposes.

5. Linking the 3D processing pipeline to the metadata creation

Within the framework of the WP4, post-processing activities run in parallel with the metadata creation. Beside the metadata for Europeana, essentially oriented for resource discovery, in a larger vision, which raises the digital preservation issues, this project is also an important opportunity to create documentation on processing pipelines (including technical and methodological aspects discussed in the section 3 of this report). In this sense, the work presented in the previous sections could also be used as a grid for capturing metadata during the post-processing pipeline.

The following figures illustrate the relation between a 3D digitisation process (including the acquisition, the post-processing and the elaboration of complementary 2D media) and the metadata creation according to the CARARE2 schema. Starting from the same physical object (piece of furniture in the Petit Trianon, Versailles), three digital assets are produced (see figure 11): the first one is a high definition 3D laser scanning of the object (results of the acquisition phase), the second one is a visually enriched geometric representation (results of the post-processing), the third one is a video animation (complementary 2D media) derived from the second 3D model. For each digital asset (see figures 12 to 14) the employed conceptual model allows describing the relationships between heritage assets, activities, actors, digital resources.

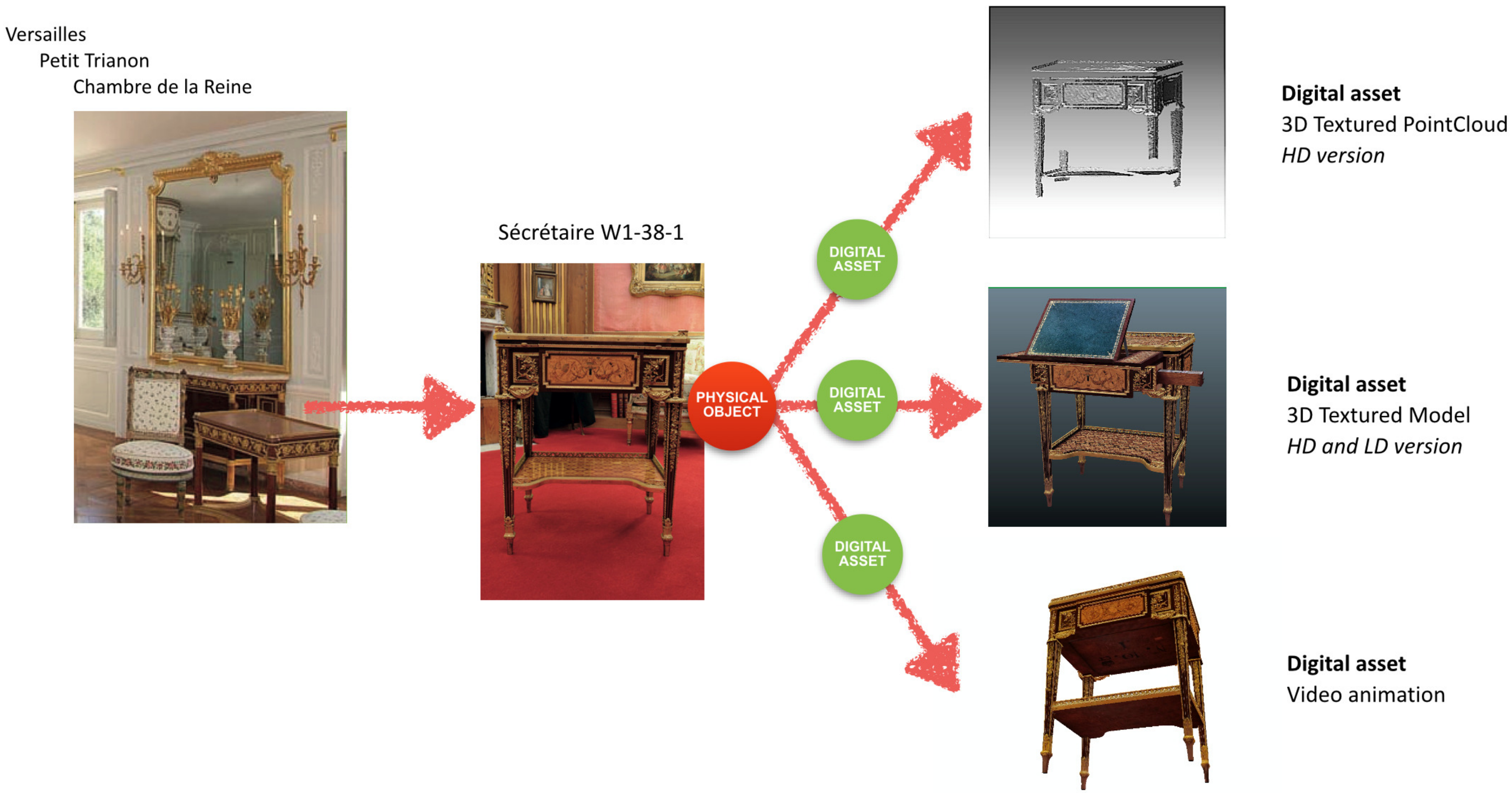


Figure 11. Three digital assets derived from the 3D digitisation of a piece of furniture of the Petit Trianon in Versailles

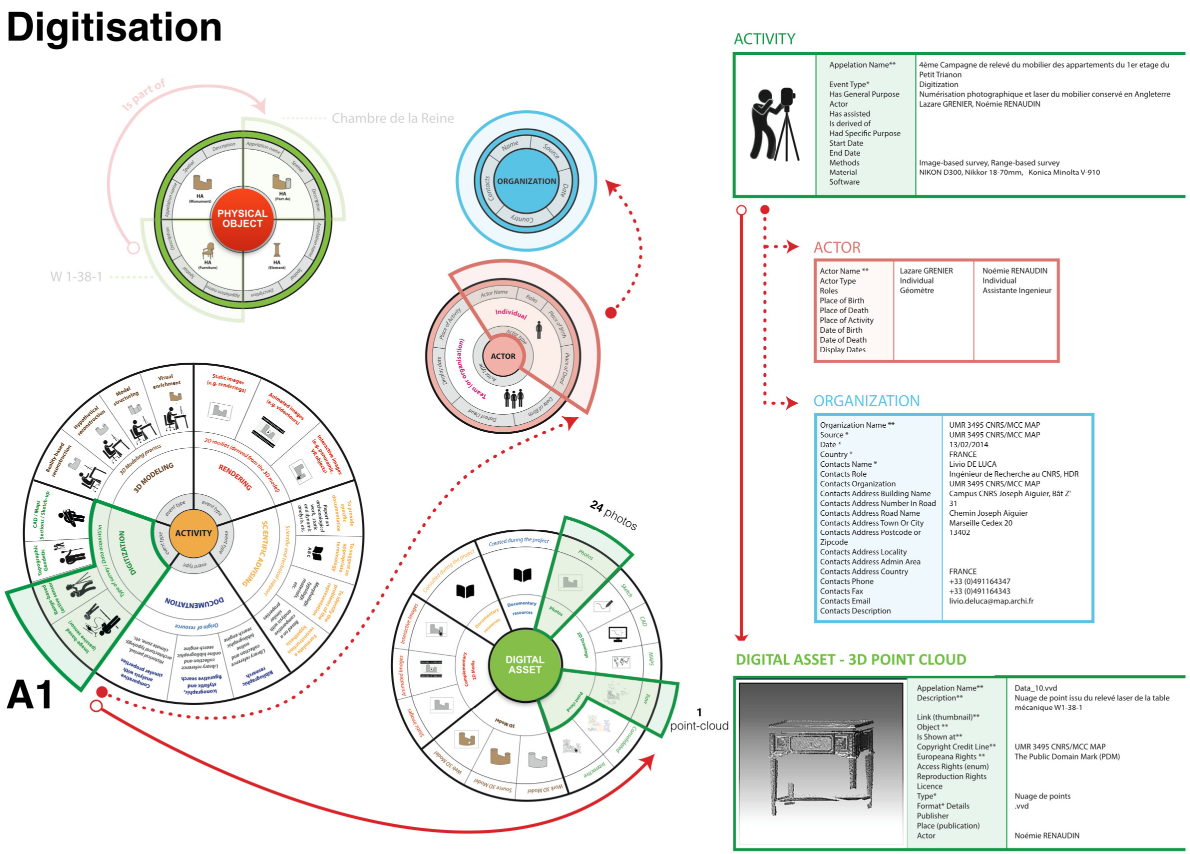


Figure 12. Relation between the 3D digitisation phase and the metadata creation concerning a piece of furniture of the Petit Trianon in Versailles

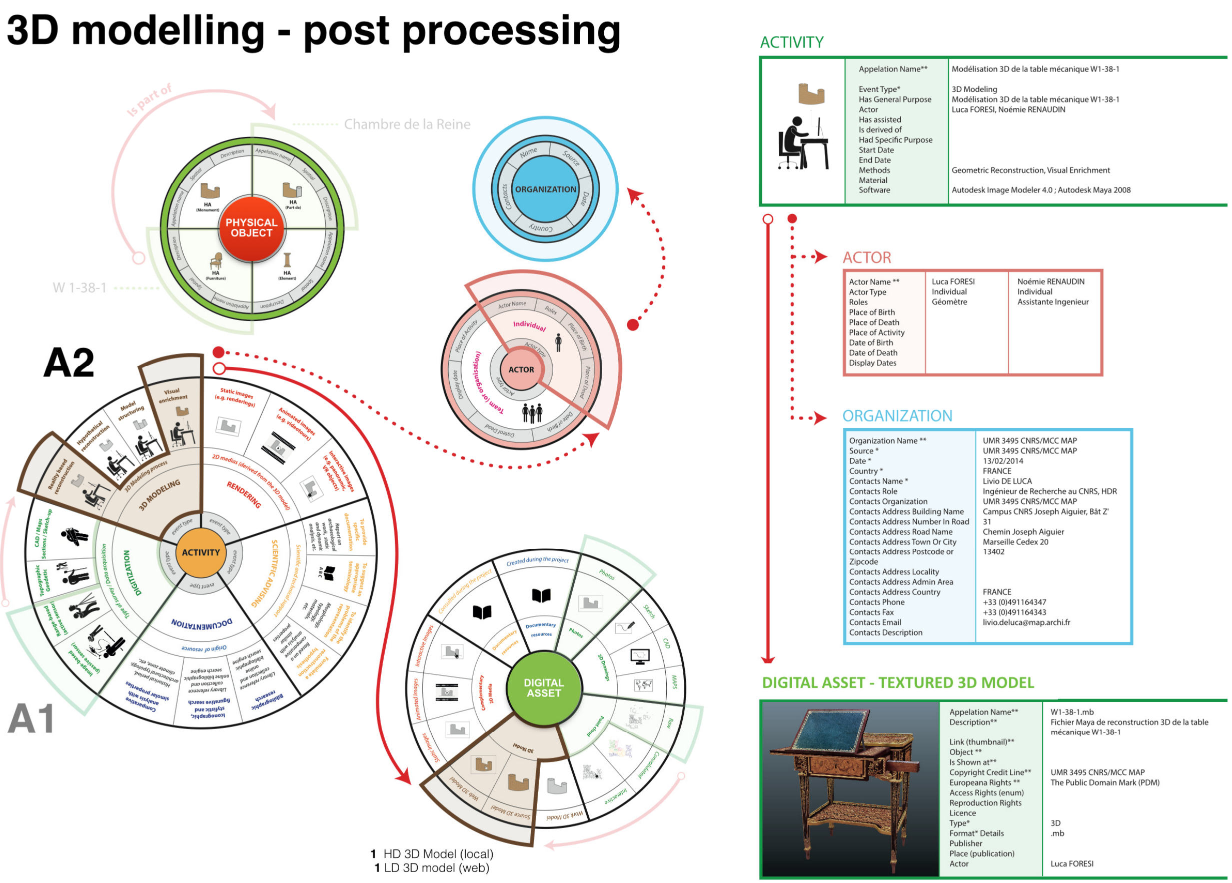


Figure 13. Relation between the post-processing phase and the metadata creation concerning a piece of furniture of the Petit Trianon in Versailles

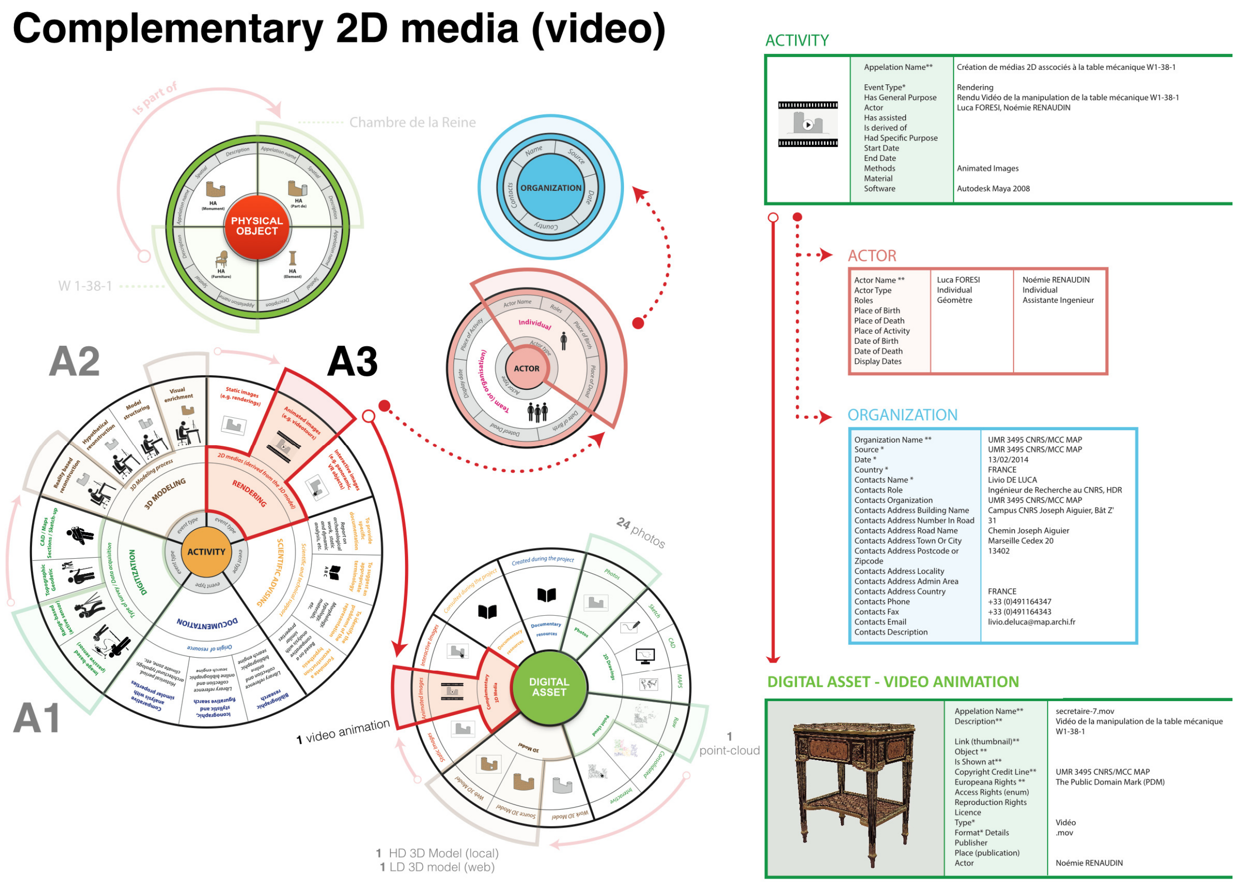


Figure 14. Relation between the elaboration of complementary 2D media phase and the metadata creation concerning a piece of furniture of the Petit Trianon in Versailles

6. Conclusions

Post-processing is a highly significant part of the 3D-ICONS pipeline in terms of the effort required and the impact on the resulting 3D-models. The work of WP4 has resulted in:

- Classification of the elementary processing steps composing the typical post-processing approaches;
- Identification of two typical pipelines with the aim to pre-orient the processing of the data through a specific final output (for web publishing purposes);
- Determining criteria for multiplying digital assets starting from a 3D digitisation campaign.
- Providing an initial grid for describing post-processing activities when creating metadata.

Besides the presented methodological and technical issues (also including the solutions applied), the management and the long term preservation of high quantities of data (raw data, visually-enriched 3D geometric representations, complementary 2D media, metadata, etc.) forms an important issue within the framework of the project. Solutions for setting-up several shared data repositories are currently being tested and evaluated within the project consortium.