A metadata enriched system for the documentation of multi-modal digital imaging surveys

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In the field of Digital Heritage studies, data provenance has always been an open and challenging issue. As Cultural Heritage (CH) objects are unique by definition, the methods, practices and strategies to build digital documentation are not homogeneous, universal or standardized. Metadata is a minimalistic yet powerful form to source and describe a digital document. It is often required or mandatory at an advanced stage of a Digital Heritage project. Our approach is to document a Digital Heritage asset by integrating meaningful data from multiple sources and multimodal imaging surveys. This article exposes the methodological and technical aspects related to the ongoing development of MEMoS – which stands for Metadata Enriched Multimodal documentation System. MEMoS aims to contribute to data provenance issues in current multimodal imaging surveys. It explores a way to document CH oriented capture data sets with a versatile descriptive metadata scheme inspired from the W7 ontological model. In addition, an experiment illustrated by several case studies explores the possibility of integrating this metadata encoded into 2D barcodes directly to the captured image set. The article lays the foundation of a three-part methodology to describe, encode and display metadata-enriched documentation of CH objects.

Keywords:
Digital Heritage, Multimodal Imaging, Digital Documentation, Metadata, Semantics.

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1. INTRODUCTION

Metadata is a key feature recurring all over the operative chain and along the data lifecycle for digital documentation of Cultural Heritage (CH). However, metadata management and conservation remain until today a challenging and tedious task. In the context of digital surveys carried out on tangible CH for the past decades metadata is created, embedded, shared but also and more often truncated, altered, or erased at each step from data acquisition to long-term archiving. Data provenance and traceability of digital based heritage documentation is a key point that has been addressed many times in various contexts (conservation, archeological or historical studies). Digital Heritage tools and methods are perpetually changing and adapting to the variety of shapes, scales, materials, and environments characterizing the richness of Cultural Heritage, hence the difficulty to transpose or

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re-use any viable and efficient solutions from one project to another. Moreover, this pitfall must be combined with a wide range of evolving imaging and capture techniques, applied in variable contexts for different purposes. From this statement, anyone can foresee that the chance of having in the near future a single, generic and standardized solution covering all possible current and future applications is close to zero. Due to novel digitization efforts, the Cultural Heritage community is collecting an overgrowing mass of heterogeneous data with a high risk that the majority of these datasets will not be reusable in the future because of a lack of documentation. Such a scenario is not so foreign, as it already occurs in our daily practice. Beyond technical issues or technological obsolescence, satisfying the minimal requirement of data provenance is an open challenge identified by the scientific CH community [Ram and Liu 2008], including the specific application of 2D/3D digitization [Carboni et al. 2016]. Furthermore, data provenance is even more important as most current studies combine multiple sources implying data fusion stimulating issues [Ramos and Remondino 2015, Al-Barakati et al. 2014].

A great deal of image-based techniques applied nowadays can be exploited to directly embed metadata on the resulting data. Different solutions exist to prevent data and metadata permanent linkage issues, such as digital watermarking and barcode integration [Dibble et al. 2007, Hill and Whitty 2021]. The first one aims to hide information for privacy or security purposes (in addition to the data integrity issue) while the main problem is at the opposite to reveal latent and valuable information through metadata. Barcodes propose today interesting features (robustness, capacity, ease of use) and a high technology readiness level. An application for CH documentation is explored in this work. Among 2D barcodes, the Quick Response code [Pandya et al. 2014] thanks to its large capacity, 360 readability and error/damage correction abilities has been experimented for the purpose of this research. To this aim, we conceived and experimented a system allowing to document the of a Digital Heritage asset from its own photographic-based surveys.

This article presents a versatile and CH-oriented framework entitled MEMoS and standing for a Metadata Enriched Multimodal dOcumentation System. MEMoS is aiming to define a operator-friendly solution to integrate essential metadata and paradata during data acquisition. The first results are presented on methodological aspects and technical implementation solutions are proposed while the main contribution related to data provenance issues in digital heritage studies is discussed all along.

2. RELATED WORKS

The Digital Cultural Heritage community has been trying for the past decade to build a shared semantic framework to enrich and link data within the umbrella of FAIR principles [Xiying and Pollock 2018]. This improvement of the CH data lifecycle is currently done at the cost of a growing complexification at each step of the operative chain, in the exchange of data provenance and information traceability [Al-Barakati et al. 2014]. For the same research aim, some natural sciences domains with many similarities to DCH research appear more advanced, or at least seem to converge more efficiently on stabilized workflows and methodologies [Huisman et al. 2021]. For a while, the DCH community has been claiming to move forward massive digitization [Santos et al. 2017, Hey and Trefethen 2003] but had to admit the important gap between humanities and E-science top

contributors (physics, astronomy, biology or earth and chemical sciences) [Hey and Trefethen 2003, Schrorer and Mudge 2017] in term of advances in data integration and ingestion. Beside this scalability gap, Heritage Sciences share a sort of modus operandi with biology and earth sciences. Indeed, in these domains scientists are collecting samples on-field, transformed into data and analyzed on-site or in-lab to extract knowledge from the combination of various technologies. The analogy can be developed further with similar if not identical material or resources involving massive heterogeneously complex samples and data obtained with variable methods [Dibble et al. 2007, Huisman et al., Plumejeaud-Perreau et al. 2019].

In this context, analogous tools and applications are reviewed according to multiple criteria such as domain adaptation, management of multimodal data, extension toward linked open data (LOD), compliance with OAIS (Reference Model for an Open Archival Information System), visualization and annotation features or barcode support. This following overview of related works isn't given for competitive comparison purposes but to place our proposal in a global framework where synergic forces may converge to improve multimodal correlation potential. Our hypothesis is to rely on interoperability to reinforce the bridges between existing and future tools instead of limiting users to adapting to a single and ubiquitous solution. Indeed, past experiences have shown the difficulty of focalizing toward a generic and standardized solution that will probably fail to obtain the acceptance of the CH community by approximating multidisciplinary and cross-domain needs [Al-Barakati 2021, Ronzino et al. 2012, Simmhan et al. 2005].

Table 1. Overview of data management-oriented tools and software packages and their respective features

	Domain	Type	Open-source	Spatialized Data	Multisource Data	Visualization	Annotation	FAIR Data	Standards compliance	OAIS	Barcodes support
CollecScience	N	Both	Y	Y	Na	Y	Na	N	Y	±	Y
CherOb	Y	Standalone	Y	SIG	±	Y	Y	N		N	Y
DLN:CC	Y	Standalone	Y	N	±	N	N	Y	±	Y	N
Aioli	Y	Web	Not yet	Y	±	Y	Y	±	±	N	Y
Memoria	Y	Web	N	N	Y	±	N	N	N	N	N
Arches	Y	Both	Y	SIG	N	±	Y	Y	Y	Y	N
Archeogrid	Y	Web	Not yet	N	Y	Y	Y	±	Y	Y	N

2.1 Collec-Science (INRAE)

Collec-Science (CS, www.collec-science.org) is collaborative software dedicated to the data management of collected samples in the framework of scientific experimentations developed by Eric Quiton [Quinton 2021]. The application domain is earth science and biology. CS is an open-source solution distributed under an AGPL license. CS helps to handle the registration, storage, conservation and sharing of two types of elements, containers and samples using many possible configurations. A labeled object is associated with free-from or normalized metadata to ensure data provenance and traceability through the places visited during its lifecycle. CS is adapted to samples collected on the field and QR code labeling is integrated to identify and track any item. A CS instance (service and related database) is commonly accessible on the web for collaborative scenarios, but it can also be installed locally to allow its use in remote places where internet connection is not accessible or stable [Plumejeaud-Perreau et al. 2019]. Despite the similarities of its collect-store-(re)use goals, it appears that the CS framework is not easily transposable to the CH application domain because of the rigid terminology necessary for its native domain.

2.2 CherOb (Yale University)

CherOb (CULTURAL HERITAGE-Object, CO) is an open-source software aiming to improve cross-analysis of CH projects based on 2D and 3D visualization with related annotations [Wang et al. 2018]. CO relies on the concept of a Cultural Heritage Entity on which the platform aggregates multiple sources coming from different imaging techniques (2D and 3D images, RTIs, CT). Using a split window viewer CO simultaneously interprets several resources but doesn't seem to provide a built-in tool to register 2D/3D data meaning whose annotations cannot be spatially interlinked. This software includes a metadata framework but is restricted to a single standard, offering users to solely use Getty Categories for the Description of Works of Art (CDWA) descriptive schema. Nevertheless, a case study provided in the software manual shows an interesting example of using QR code integration to automate information extraction. Additionally, CO includes a video generation feature capable of creating virtual storytelling valuable for dissemination purposes. Unlike the next example, CO doesn't include a long-term conservation component, except for the XML created and used to generate a PDF report. Surprisingly, despite plenty of relevant and interesting implemented features to improve CH analyses, the CO system does not present any abilities or opening yet toward LOD.

2.3 Digital Lab Notebook Context Capture (Cultural Heritage Imaging)

Recently, Cultural Heritage Imaging (CHI) made a first attempt to transpose the laboratory notebook for CH oriented projects with the release of Digital Lab Notebook: Context Capture (DLN:CC). DLN:CC is a stand-alone open-source software released under GNU license Version 3. The aim of this software is to document the making of all the digital resources related to a CH project [Schrorer and Mudge 2017]. DLN:CC enables metadata-enriched documentation at three levels: project, session and capture set. This way, users can collect, organize and re-use the GUI information stored (only locally) in a PostgreSQL database. Aware of the ongoing turnover of CH experts to FAIR data, the package includes an X3ML mapping engine linked to a conceptual model in CIDOC-CRM compliant description to export a project and linked resources in RDF format. It also has an interesting feature of formatting data into a Submission Information Package (SIP) in internationally compliant formats,

namely METS and BagIt wrapper. However, DLN:CC has remained since 2018 in a beta-version and some bugs and limits (restricted to few computational photography techniques) are restraining its wider use and dissemination.

2.4 Aioli (MAP Research Unit)

Since 2014, our research unit has been developing AIOLI (www.aioli.cloud), a reality-based collaborative semantic annotation web-platform. It allows spatial registration of multimodal imaging as long as it is compliant to photogrammetric routines. Other resources can be linked to a semantic spatial annotation anchored to 2D and 3D region as shown in this public project: https://page.hn/qaxsdt. Between all those CH oriented platforms, AIOLI is the only tool which allows users to build spatial correlation between data and semantic enrichment. Each annotation directly drawn on the 2D/3D viewer can be structured and labeled freely or by calling on thesauri and controlled vocabularies while corresponding regions are propagated to the scene and enriched by geometrical and statistical features (normals, curvatures, bounding box, barycenter, color palette, etc). Links between MEMoS and AIOLI are numerous and could be implemented quite rapidly as QR code decoder is already implemented. Some examples include automatic geolocalisation, inviting collaborators, temporal state management, loading a predefined template for annotations or terms from thesauri, and linking to uniform resource identifiers (URIs) and universally unique identifiers (UUIDs). On the semantic side, an interesting bridge with MEMoS is foreseen as AIOLI processes, including annotation, have been recently formalized in CIDOC-CRM.

2.5 MEMORIA (MAP Research Unit)

Memoria is an Information System (http://memoria.gamsau.archi.fr/projet/) aiming to record the process through which a digital resource or activities were achieved [Dudek and Blaise 2017]. Memoria is a web platform enabling to describe and depict a scientific result especially in historical and heritage sciences. Users can build the research process directly through the interface, including the tools, the workflows and even the choices made during their work to create a digital output. Memoria is based on an internal and collective initiative to create a wheel of activities (including digital surveys) with corresponding definitions for each term. Interaction with the database envisioned as a knowledge-based systems are made directly via the website or through PDF forms, where users can add or modify descriptors to document instruments, objects of studies, temporal coverage, or format-related information. Bridges between MEMoS and Memoria are already planned either to use MEMoS to initiate or complete a description or alternatively, to use the Memoria interface and database (authors, affiliation, equipment, etc,) to prepare and generate MEMoS compliant metadata.

2.6 Arches (Getty Conservation Institute)

Arches is defined as an inventory and management platform dedicated for heritage institutions and practitioners (www.archesproject.org). It is a specific purpose-built software aiming initially to provide effective support of heritage conservation and management. Arches offers a complete community driven system, free and open source (AGPL3), available on-line and off-line with mobile support. It includes several features like GIS based visualization, controlled vocabularies, annotation

support or CIDOC-CRM compliance. An extension called Arches for Science has been announced for conservation sciences purposes.

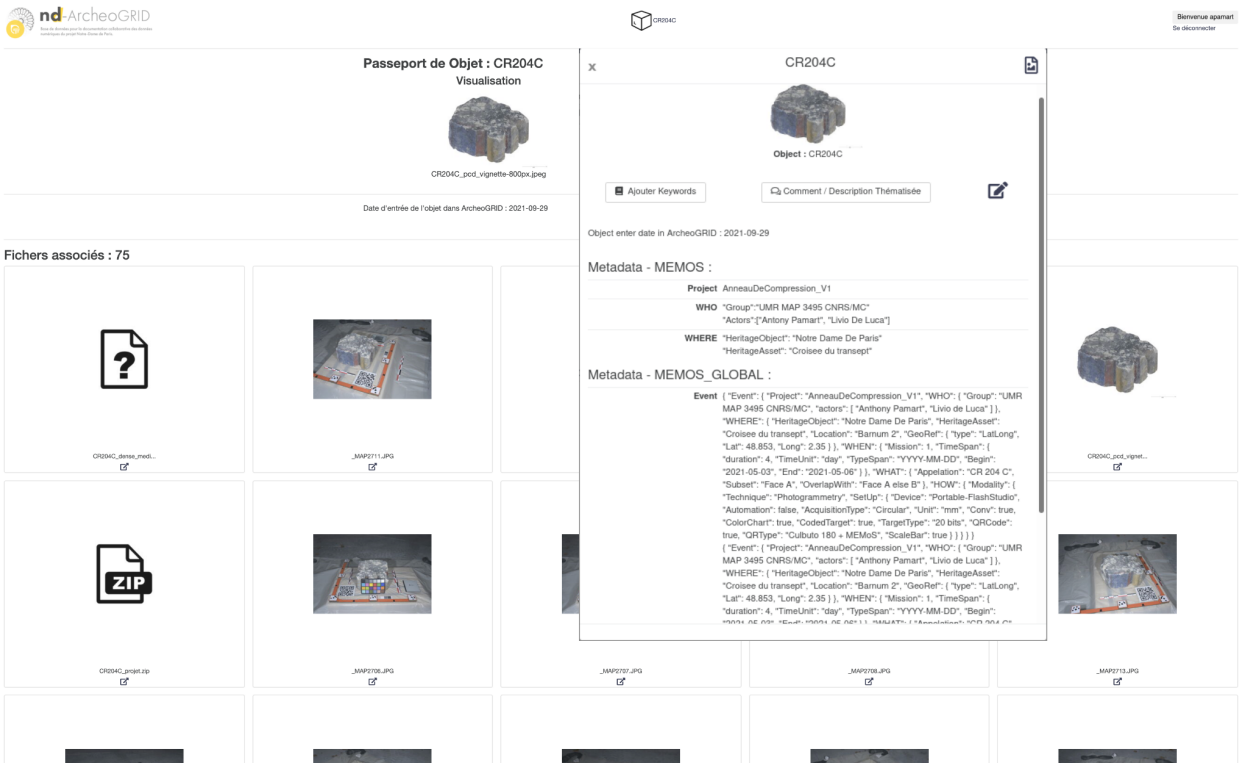

Figure 2. Screenshot of the nd-ArcheoGRID platform showing the ongoing work of automated MEMoS based metadata filling and association

2.7 ArcheoGRID (Archeovision)

ArcheoGRID is a web-interface (www.archeogrid.fr) that facilitates and encourages the collaborative management of documentation for 3D projects in digital humanities all the way to data sharing, publication and first step toward archiving. For more than a decade, Archeogrid has been used as a portal to access and explore semantically enriched digital resources according using different standard exchange protocols in force (DublinCore, RDFa, OAIS). It allows users to view, browse, query and annotate the documentation gathered according to their descriptive metadata manually filled or batched at file, object, site or collection levels. It aims to host textual, iconographical but also scientific or research oriented data including 3D models and prepare them to deposit in the National 3D data Repository (3d.humanities.science) and further toward their long-term archival compliant CINES prerequisites handled by a stand-alone software (aLTAG3D). ArcheoGRID is free-access and the data are hosted in HumaNum (https://www.huma-num.fr/about-us/) a Digital Humanities Infrastructure with which large scale harvest methods are currently envisioned at European and international reach.

3. MULTIMODALITY IN DIGITAL CULTURAL HERITAGE STUDIES

A twofold assumption has to be taken into consideration to develop a close definition of multimodality in the DCH domain. First, there is an ongoing evolution of digital-survey-based practices from a linear to cyclic workflow [Limp et al. 2013]. Indeed, past, and current innovative projects including EU initiatives (COST-COSCH, SCAN4RECO, ITN-CHANGE) are no longer one-shot and isolated case study applications that build and explore a single sourced digital model. Instead, DH innovation is related to complex scenarios where the digital model is used to represent, renew, and discuss over time the added knowledge of multi-source virtual reconstruction. Subsequently, it we cannot consider our productive methods made of straightforward I/O operative chains but rather we should see them as a part of a system. Involving the principle of a systemic approach helps to embrace the multiplicity and the complexity of DH practices and supports the definition of multimodality proposed hereafter.

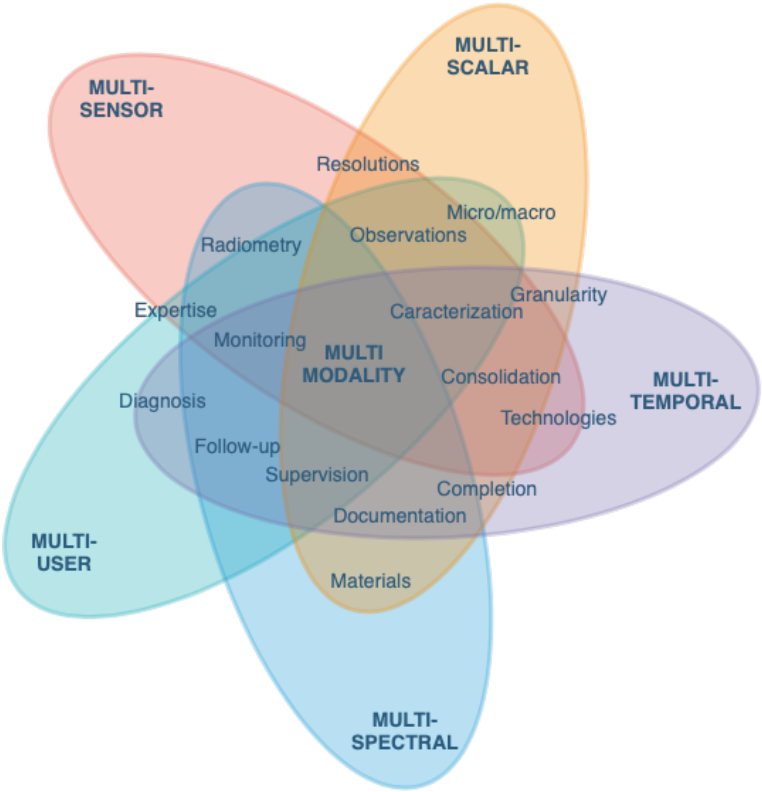

Figure 3. Diagram of multimodal layers in CH domain

Several disciplines have defined (multi)modality, including semiology, psychology and informatics. In the Human-Machine Interface (HMI) domain, a modality is an action with which a user can interact with a system [Nigay and Coutaz 1993]. The multimodality is therefore defined by the cooperation between several modalities. In addition, the same authors advanced the concept that

multimodality was presumed to have informational or semantic added value only if it was related to data fusion. If we transpose the DH object as a system, we can assume that CH experts use multiple modalities to interact with a digital CH asset and are currently trying to combine them efficiently to enrich the knowledge on the physical CH object. A digital representation can therefore be considered as multimodal if it is made of at least two cooperative modalities. In DH current practices, it is common to mix data from different sensors, resolutions, scales, spectrums, temporal states and users - acting as many modalities - aiming to build a representative digital documentation of a CH object.

From this definition, it is possible to state that CH practices are commonly and intrinsically multimodal as they usually involve some of the cross-modalities above-mentioned. Taking into consideration all those variables, data provenance surely will become - or has already become - more and more brain teasing. It is inefficient and problematic to carry out a multi-source reconstruction for data fusion after data is collected, which is a motivating factor behind why a solution is needed to address or integrate this issue during data acquisition. Indeed, in most scenarios exploiting digital models, a metadata-based description is mostly achieved - and required - in the advanced step of a DH project, usually when data are going to be circulated to the scientific community, the institutions, or the public. It is consistent that the documentation needs are higher when data has the maturity level to fit collaborative work, end-user deposit or long-term archival objectives. However, one can have the intuition that replacing or strengthening metadata could be a valuable solution to reinforce globally CH-oriented methodologies.

4. MEMOS, A METADATA ENRICHED MULTIMODAL DOCUMENTATION SYSTEM

MEMoS is currently envisioned as a three-part framework to sequence, describe, encode and display meaningful metadata attached to an image set at the time of capture. The description is performed beforehand using a structure inspired from the W7 ontological model as described in Fig. 4. The encoding is achieved with common and simple 2D barcodes. The display is illustrated in the following section 4.3, showing MEMoS uses in different case studies. Our approach is currently at an experimental testing stage. The results presented below were obtained using several libraries and softwares, but MEMoS would benefit from a dedicated software and hardware framework as depicted in the illustration below (Fig. 4).

The concept behind the use of barcodes to incorporate metadata into the acquisition stage has an analogy to the well-known clapperboard used in cinematographic industry. The clapper-board board deserves two objectives. First the slate itself is used to keep a trace of useful information for the video shoot, corresponding our metadata schema encoded in the QR code. Second, the sharp clapping noise produced by the board signifies the beginning of a sequence, in our scenario corresponding to a new data capture. The analogy of the clapperboard can also be extended to its productive stages. In the same way it is used for film editing, QR code detection can help to structure, tag, sort, and filter complex data set sequences according to their linked metadata.

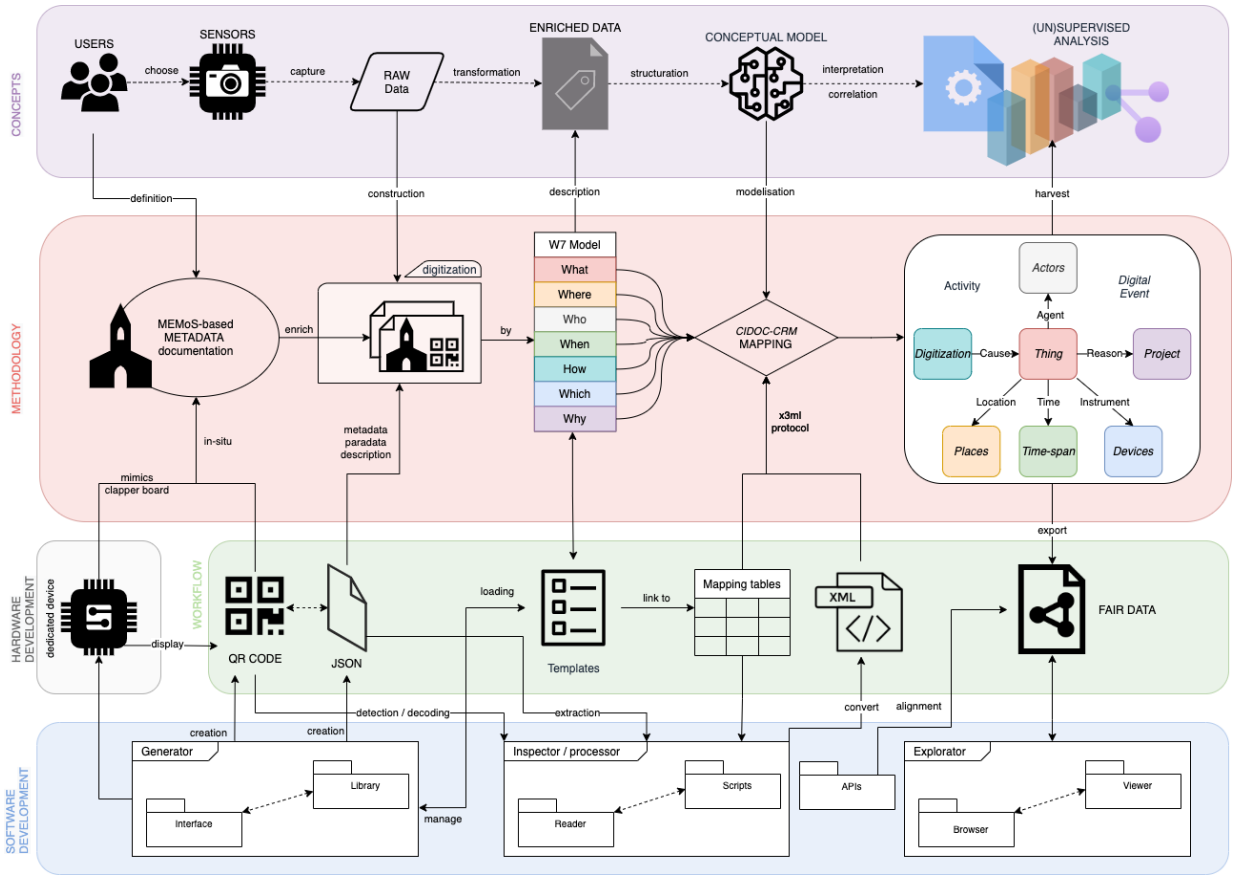

Figure 4. Synthetic diagram of the expected MEMoS all-in-one framework

4.1 DESCRIBE: a w7 inspired metadata description structure

In CH, metadata is essentially addressed to memory institutions (museums, libraries, documentation centers) while the underlying technical considerations are the prerogative of data-scientists. Nowadays, there remains a significant leap between data creator/provider ("on field") and the metadata holder/user ("in library"). Attempts to converge to a generalized and standardized solution have already been explored [Ronzino et al. 2012, Steiner and Koch 2015] always without reaching a consensus. The most commonly used standards are Dublin Core, MIDAS, POLIS, LIDO [Pitzalis 2011] and CARARE 2.0 [D'Andrea and Fernie 2013]. However, most of them present strong limitations for their seamless adaptation to multimodal acquisitions, hence a DICOM inspired method has been recently presented [Daffara and Gobbetti 2018] but has been conceived for a specific purpose of aging analysis. The constraint of a mandatory (even is unused or not applicable) string is the common negative point of all descriptive metadata filling forms. Photographs, images, or visual resource-related metadata are commonly addressed through EXIF while their association with other standards like XMP or IPTC [Saleh 2018] is an open discussion [Reser 2012]. Nevertheless, those formats are made for technical metadata and cannot encompass other kinds of paradata mobilized for the studies concerned. Standards are usually conceived on purpose to serve a specific application

making them inevitably not fully applicable to other research aims, this work included. Therefore, instead of contouring existing standards and their respecting limitations, the choice has been made to call on an eloquent, pragmatic and flexible structure to organize the metadata.

The W7 model has been conceived for data provenance purposes and aims to be flexible enough for cross-domain usages [Ram and Liu 2019]. Interestingly, the W7 model has also been chosen in the biological microscopy domain and also to prepare data for FAIR uses [Huisman et al. 2021]. Thus, we can ensure that the model is adapted to the CH multidisciplinarity and could be extensible beyond the context of this study. It consists of interconnected components; namely, what, when, where, how, who, which and why. These components can be mapped at ontological level to subsequent "concepts". In the context of our application, those tags elements can contain meaningful information to describe a Digital Heritage resource, using the following structure:

- Activity (Digital Event)
    - Who
    - Where
    - When
    - What
    - Which
    - How
    - Why

What is meant to provide information on the CH object or the part of it being documented.

Who defines at a semantic level the "agents" involved and can refer to institutions, research units, groups or individual experts.

Where is used to describe the space concept, aiming to localize the place of the CH object and/or delimit the area of the survey.

When is related to time information as a means to bound the duration or temporal aspects of the event described, or time-related information on the artifact.

Which is the section dedicated to reporting the hardware/software implications such as instruments, devices or applications and other supports used for data capture.

How encompass the "action" sphere and give a place to expose methods, techniques or procedures exploited.

Why is dedicated to including contextual contents and purposes or any information that motivated the action performed. The spectrum of this section is vaguer than the previous but can be filled with elements related to the project itself or the expected outcome of the dataset.

In this way, any *Activity*, understood as a flexible digital event (project, mission, a capture set, a subset or even a single resource) is therefore defined by the cross-relations between the seven elements enriched with free-form and context-dependent descriptive metadata.

By convening this W7-inspired structure, the choice has been made to rely on metadata abilities for interoperability instead of constraining the use of a standard or imposing a new one. The choice of this flexible and open model doesn't prevent the use of different standardized metadata classes into their corresponding sections. The non-rigidity of the MEMoS scheme also comes with a significant limitation because of the higher risk of scattered or heterogeneous metadata. Hereafter, a proposal is made to adopt this W7 structure at the section level with a generic purpose CIDOC mapping (see Fig. 5), providing minimal constraints for different community needs (team, project or expertise field). Afterward, other communities could agree to a specific template, and improve and deepen the mapping level for more specific cases.

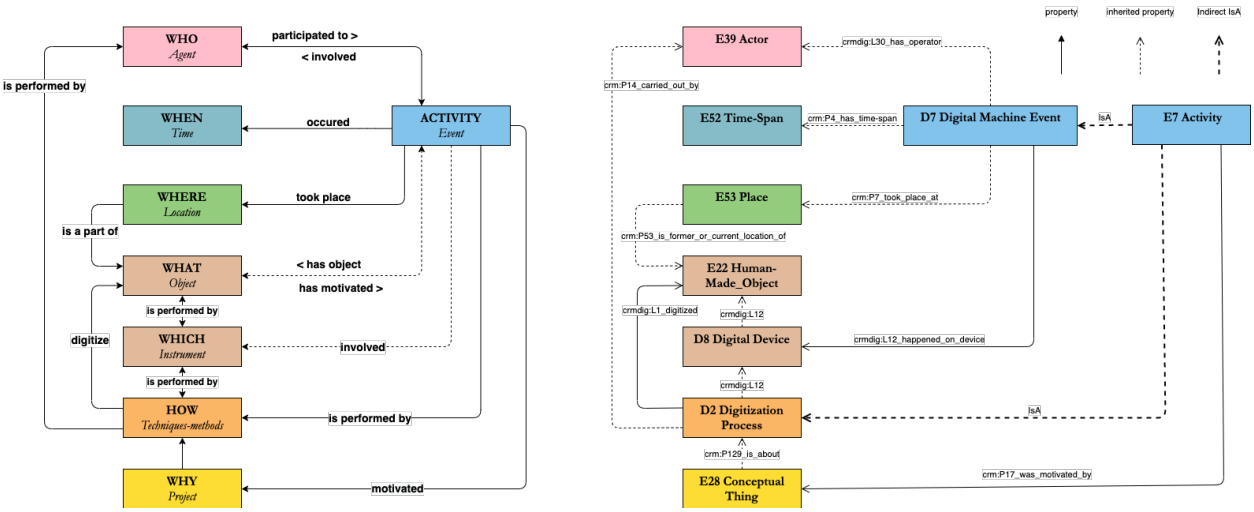

Figure 5. Example of preliminary scheme (left) to derive a MEMoS description (section level) into a CIDOC-CRM compliant mapping (right).

4.2 ENCODE: a user-friendly and versatile solution based on 2d barcodes

2D barcodes present an efficient and simple way to encode data but remain strongly limited in terms of storage capacity. Therefore, an optimal solution has to be found to maximize the volume of the metadata encoded while preserving a good decoding and extraction result. The first idea was to shortcut the data stream integrating FAIR ready description (e.g., in RDF or in JSON-LD serialization; but this implies the pre-existence of a semantic framework prior to data capture, and the verbosity of those formats were too limiting. For the same reason, the second choice of markup languages (XML) predisposed to descriptive metadata standards and exchanges was rejected because of the necessity of repeated markups, which implies a high percentage of unused characters. The best compromise was found in JSON for multiple benefits: mainly, its syntax, data type, support minification and parsing/exchange facilities. Future work will try to extend possible input format to even simpler alternative like YAML or CSV.

A short review of 2D matrix barcodes has been made to choose the most appropriate solutions. The first criterion is a large storage capacity, as the aim is to embed quite extended metadata description schemes. The second criterion that could complicate the use and the implementation of barcodes is

accessibility, as some solutions are license-based or proprietary. The last criterion is the radio colorimetric behavior as the barcode must be stable in a multi-light environment or anticipating a potential use with multispectral devices. The most known is the "Quick Response Code" (QR code), which has the benefit of being widely disseminated (libraries to encode/decode, scanning apps, etc.) but they have a limited capacity of 4296 alphanumerical characters. Moreover, this maximum capacity corresponds to a 177x177 module emphasizing the symbol size if combined with an error high correction rate (basically redundancy of data) could lead to a QR code bigger than a CH fragment. This issue could be resolved using QR code splitting method, if the capacity is the limitation, some techniques like multiplexing can be exploited [Abas et al. 2016]. The Denso Wave company developed the iQR code with 80% extended capacity; this technology could be used to embed up to 40,000 characters into a 422x422 module or to minify a symbol size for display purposes (adaptation to barcode and the scale of the set-up). Contrary to its predecessor, iQR has not been released as an open standard; that could limit use, development, and dissemination. For the development of Microsoft Tag Service, the multinational presented the High-Capacity Color Barcode (HCCB) [Grillo et al. 2010] and later the HCC2D with encoding capacity up to 2KB/sq2, but this promising solution was discontinued in 2015. More recently, other solutions [Melgar and Farias 2019] including Just Another Barcode (JAB) [Bechtold et al. 2020] has re-introduced polychromy into 2D barcodes. For the same volume of data, a QR code should be 2.5 times bigger with comparable error compensation performance. JAB source code also has the benefit of being released under GNU LPGL. For this work, a monochromatic QR code has been chosen but JAB presents an interesting alternative especially if its robustness is validated with multi-band imaging.

At the current stage of development, python-based libraries (PyZbar or qrcode 7.3.1) or free solutions (QR-Studio, InkScape) were tested to generate barcodes from a single or a batch of JSON files. Moreover, for this preliminary stage the choice of a static solution (JSON file embedding) has been made for the benefit of encrypting human readable content into the barcodes. However, the alternative of a dynamic QR code, in which a simple URL or URI is encoded instead, could offer editable metadata at the cost of relying on a purely web-based system. In this scenario, a barcode is used to embed a unique identifier (UUID) linked to a MEMoS platform allowing to create and edit in a more flexible and collaborative way. This solution will also have the advantage of limiting capacity needs and therefore the possibility to use more compact and robust barcodes (e.g., semacode or datamatrix).

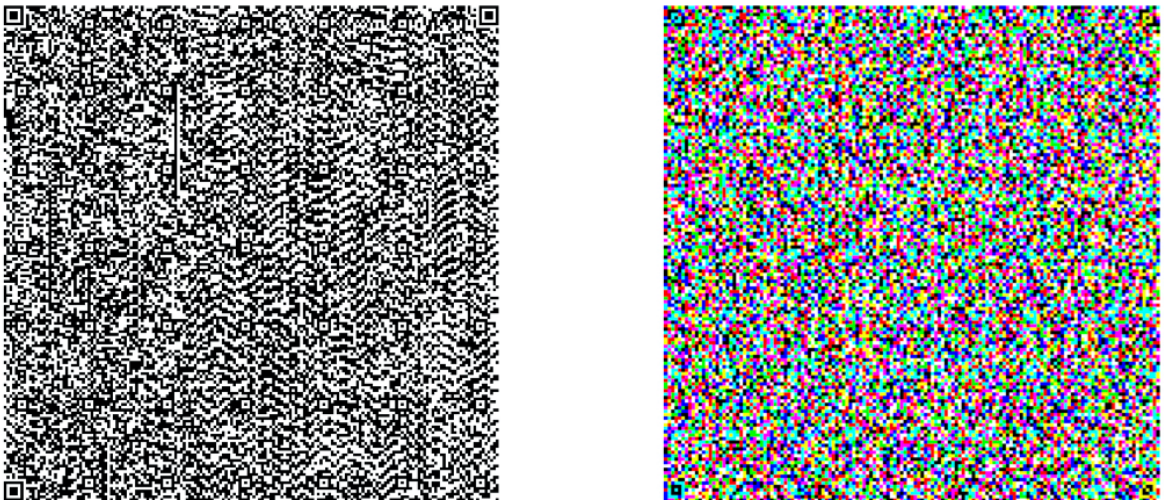

Figure 6. Example of MEMoS template expressed in JSON structure with keys type and values (top) embed into barcode using QR-code (bottom-left) and JAB (bottom-right) encoding

4.3 Display: Experiments on Variable Use Cases

In this section, some illustrated case-studies are proposed to demonstrate MEMoS' versatility and operability, even at the prototyping stage, to document some recent projects and experimentations. These use cases are genuine projects and acquisition campaigns from the MAP laboratory and close scientific collaborators where MEMoS has been used to document data acquisition at different levels.

4.3.1 Project or mission or one-shot level documentation

For this experiment made in November 2019 a unique QR code has been integrated to a calibration chart along with other coded targets. The chart was moved to different areas of the survey, each one represented with a detailed orthoimage a scene of the south wall painting previously surveyed by a global orthomosaic. The aim was to test the detection and decoding of a QR code while varying sensors and resolutions. The QR code was integrating synthetic and basic information as an attempt to memorize structured metadata to help data management of the digital collection from the Notre-Dame des Fontaines chapel in La Brigue, detailed in subsection 4.3.5.

Figure 7. Example of MEMoS QR code integrated on a photogrammetric scale bar to document an orthophoto mosaics acquisition campaign.

4.3.2 Object level documentation

This scenario is illustrated by data sets from an imaging practical workshop for the Swiss Conservation and Restoration Campus. In this context, each group of students was asked to analyze different objects with several imaging techniques (including photogrammetry, RTI and infrared thermography). MEMoS was used experimentally to encode the acquisition stage including metadata and paradata related to the group, the technique, and the object documented. As an example,

information such as material, techniques and alteration were integrated as the aim of the course was to assess and understand which techniques enable or help the interpretation of observable degradation phenomenon and mechanisms (see WHAT section in Fig. 8).

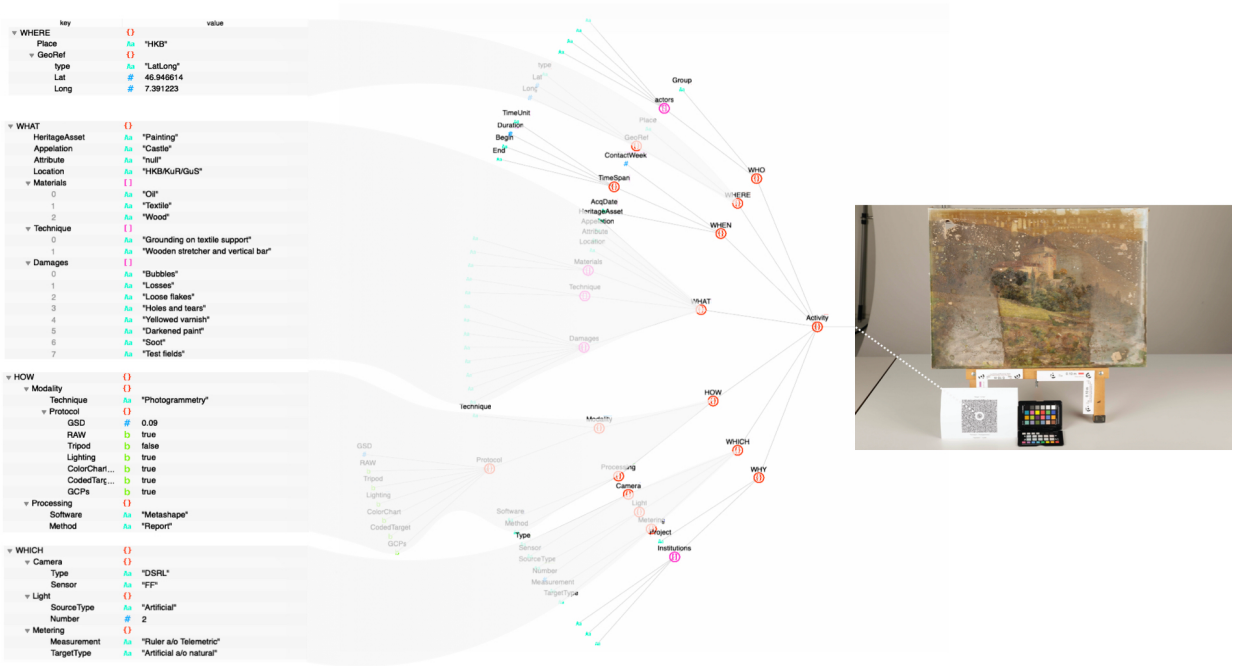

Figure 8. Example of MEMoS QR code and embed metadata captured alongside colorimetric chart prior to photogrammetric acquisition.

4.3.3 Collection level documentation

Since the fire of Notre Dame de Paris, our laboratory has been involved in the scientific worksite to provide meaningful and useful insights for the ongoing restoration and reconstruction process, by means of a digital survey. As all data collected aims to be integrated in the digital clone – made accessible to all scientists involved. Through an augmented 3D viewer, data provenance reaches unparalleled levels in this project. The MAP laboratory has been commissioned, among other things, to digitize the architectonic fragments of the destroyed crossroads of the transepts. Each fragment from the keystones and the oculus revealed during clearing aims to be replaced in their initial position in the digital double. In this context, each 3D model has to be tracked and associated with cross resources (pictures, photogrammetric image set, database, etc.) all along the virtual anastylosis. For this purpose, MEMoS has been deployed to generate from the acquisition stage a metadata schema to support a multi-purpose data provenance aligned with the Notre Dame digital framework and tools (Fig. 9). One result of this case study, addressing the automation of metadata filling into NdArcheoGRID, is detailed in the following section and illustrated in Fig. 2.

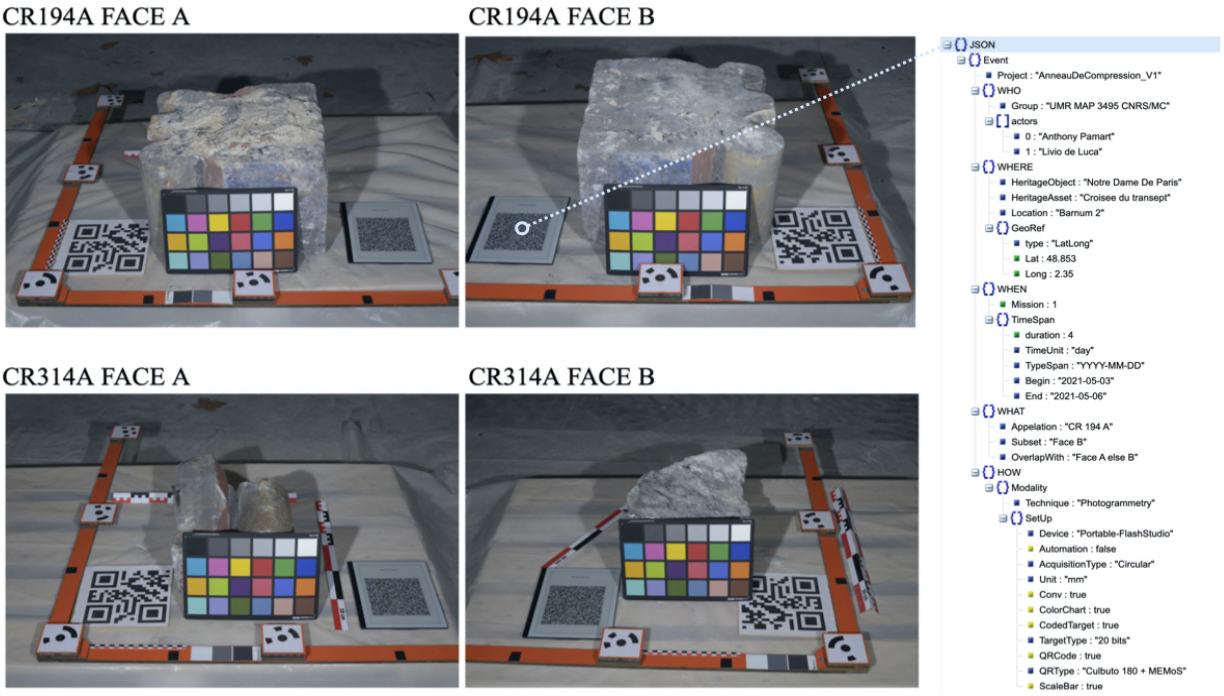

Figure 9. Example of MEMoS QR codes displayed on e-ink device and integrated on a photogrammetric set-up to document uniformly a whole collection of lapidary remains from Notre-Dame de Paris

4.3.4 Dataset-level documentation

As introduced in previous sections, MEMoS' key target is the documentation of a multimodal digital survey. In this domain, current practices indeed involve generally more than one technique, scale, or spectrum to document a single temporal state of a CH object. Such data acquisition campaigns are usually complex in the number of devices and amount of expertise required to prevent data fusion issues. In practice, multimodal surveys are actually sequenced or structured similarly to filming, hence the idea of using the MEMoS QR code system as a clapper-board. The example given is a "simple" multimodal acquisition held in the Saint-Martial chapel from the Palace of the Popes in Avignon combining laser scanning, panoramic and different sequences of close-range photogrammetry. Each subset of the data acquisition protocol (A, B, C, D and E) was documented with associated metadata coded into a barcode exposed and captured "onsite" during its corresponding acquisition stage.

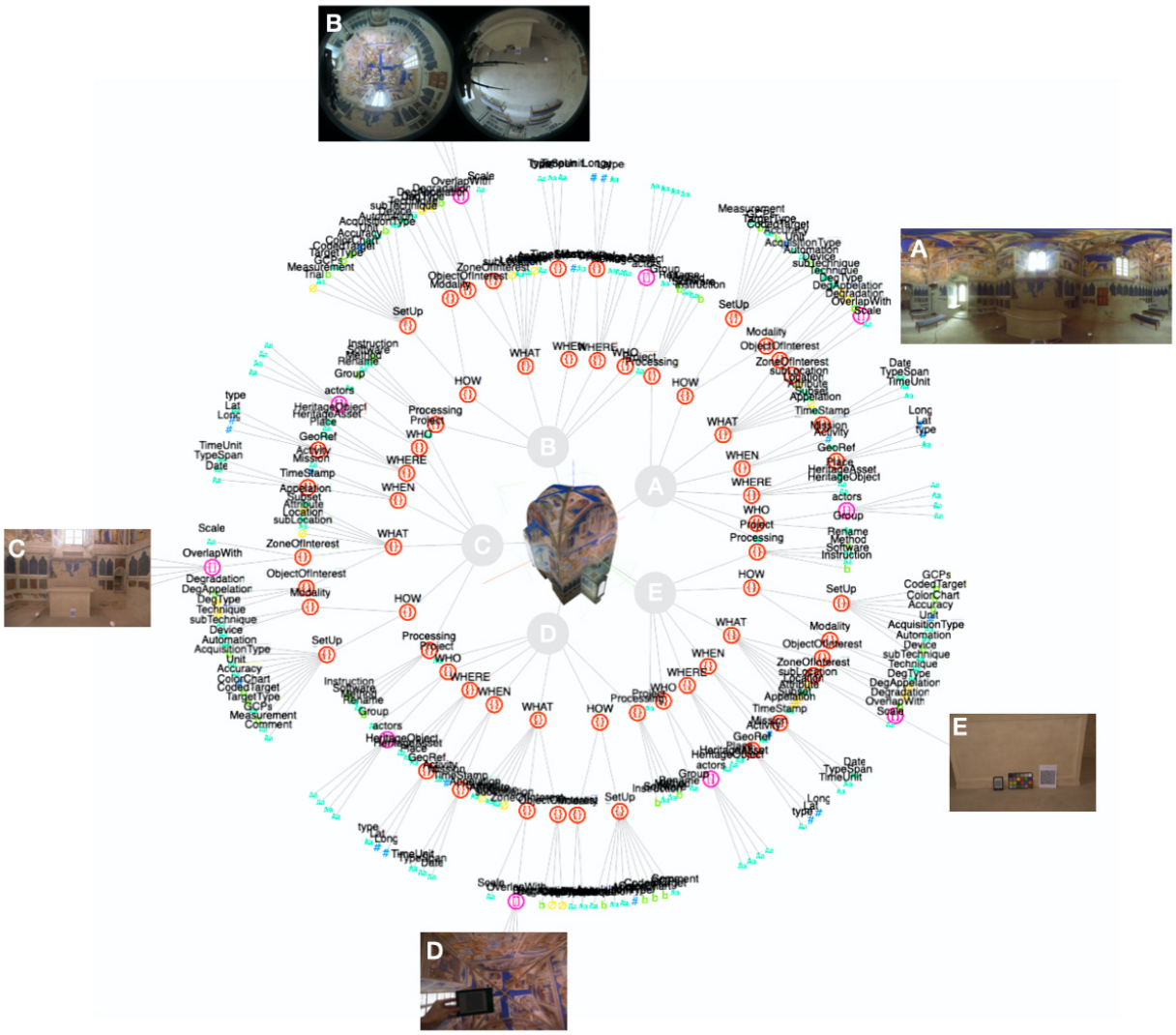

Figure 10. Example of MEMoS-based visualization from a sequence of multimodal imaging surveys composed of TLS (A), 360 photogrammetry (B), CRP on Walls (C), Vaults (D) and close-ups on wall painting and detailed elements (D).

4.3.5 Multi-level documentation

As the MEMoS experiment is a recent initiative, a complex scenario has been simulated by describing a posteriori numerous acquisitions made in Notre-Dame des Fontaines chapel in La Brigue, from 2016 to 2019. Since then, this CH object has been included in different research programs during which an important volume of data has been acquired. On the basis of 1 or 2 missions per year, although the data were collected by the same team and some close partners, a large amount of data remains unexploited, unmerged or even unprocessed. In this context, those data have been retrospectively described using MEMoS JSON in order to remind what has been done, where and when, by whom,

using which technique, for what purpose. Once compiled and combined with the metadata extracted from capture sets, the idea is to use those JSONs to give an overview and a better understanding of the digital documentation (see delta comparison presented in Fig. 11). Future work will focus on InfoViz based representations to understand, manage, explore or exploit digital multimodal documentation. The idea behind this work is to evaluate MEMoS for a dual use - a priori - by encoding metadata directly on capture sets, or to document - a posteriori - past digitization activities in a retrospective approach.

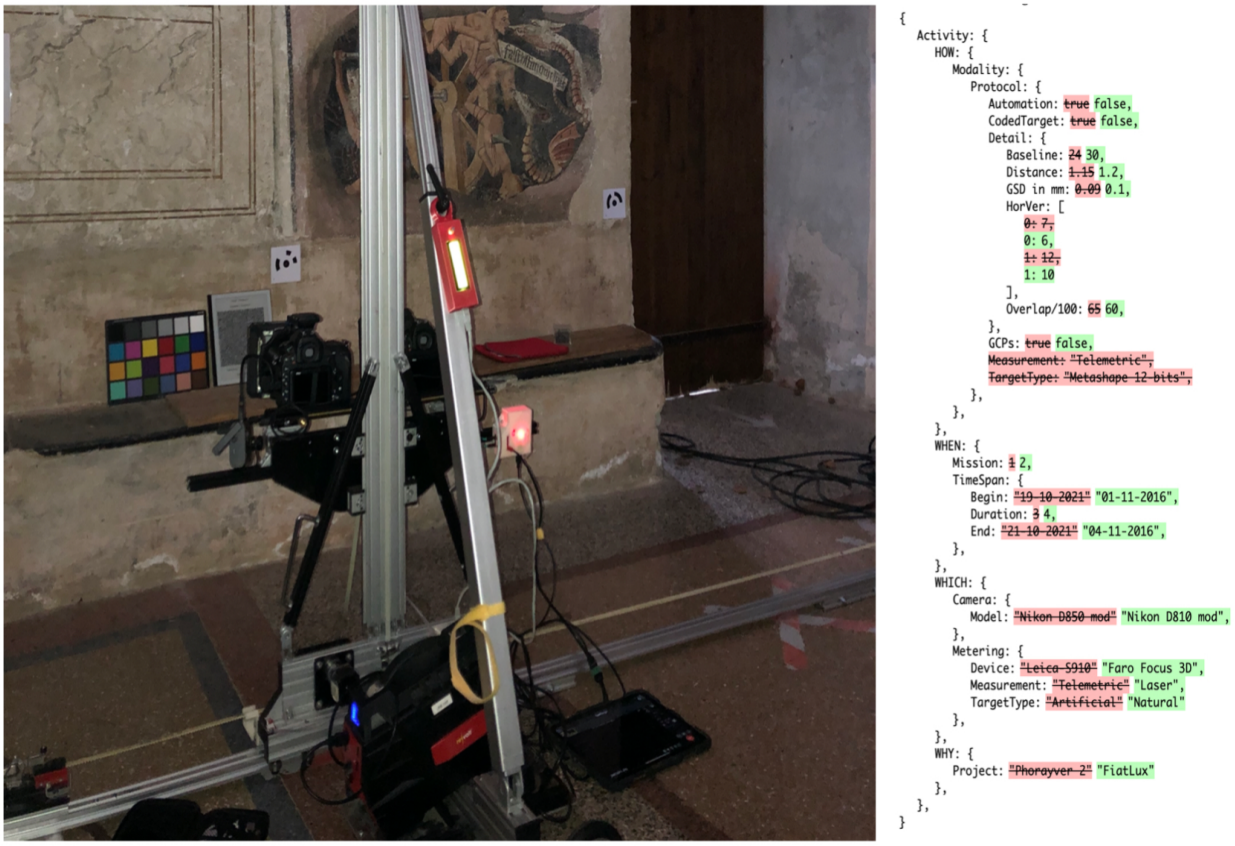

Figure 11. Highlight of differences between two multi-temporal acquisitions on the same area from a multispectral photogrammetric rig using JSON-based delta comparison.

5. LIMITS AND PERSPECTIVES

Although the technical hardware/software implementation is currently at an early stage, MEMoS has already provided promising results. Above the added value of having self-documented data sets illustrated by the case-studies, other outcomes have been experimented. Unsurprisingly, MEMoS appears to be a time-saving method to sort, organize and even apply some preprocessing steps exploiting the linkage between data and metadata. The most interesting results were obtained with the collection-level based documentation applied for the digitization of the lapidary remains from Notre-Dame de Paris (Fig. 2 and 9). MEMoS has been integrated as a metadata scheme in the

ArcheoGRID shared deposit platform. Therefore, for each JSON file detected in the arborescence, a specific routine has been developed to create a digital collection associating a virtual object with all of its corresponding resources (images, point clouds, etc.), and the extensive metadata described using MEMoS. With this experiment, a fully automatic metadata verification and completion has been achieved, greatly improving data provenance and lineage from on data capture to a centralized and shared repository.

Quite obviously, MEMoS is oriented for image-based surveys and is fully compliant with photographic-based techniques (photogrammetry, computational photography, and technical photography) even though some works use 2D barcodes patched on images [Hill and Whitty 2021] as a possible way to extend the compatibility to other imaging techniques. On a technical side, the main limitations are related to the uncertainty of complete or successful decoding, our experiments showed some difficulties in the case of multi-resolution and or multi-spectral approaches. An integrated framework (Fig.4) might be able to prevent and adapt inadequate symbol size according to a sensor definition and scaling system. On a methodological side, the non-rigidity of metadata tags integrated in a MEMoS structure could contribute to the issues of metadata sparse quality and heterogeneity. On this point, our position is that non-homogeneous metadata are always preferable to undocumented data.

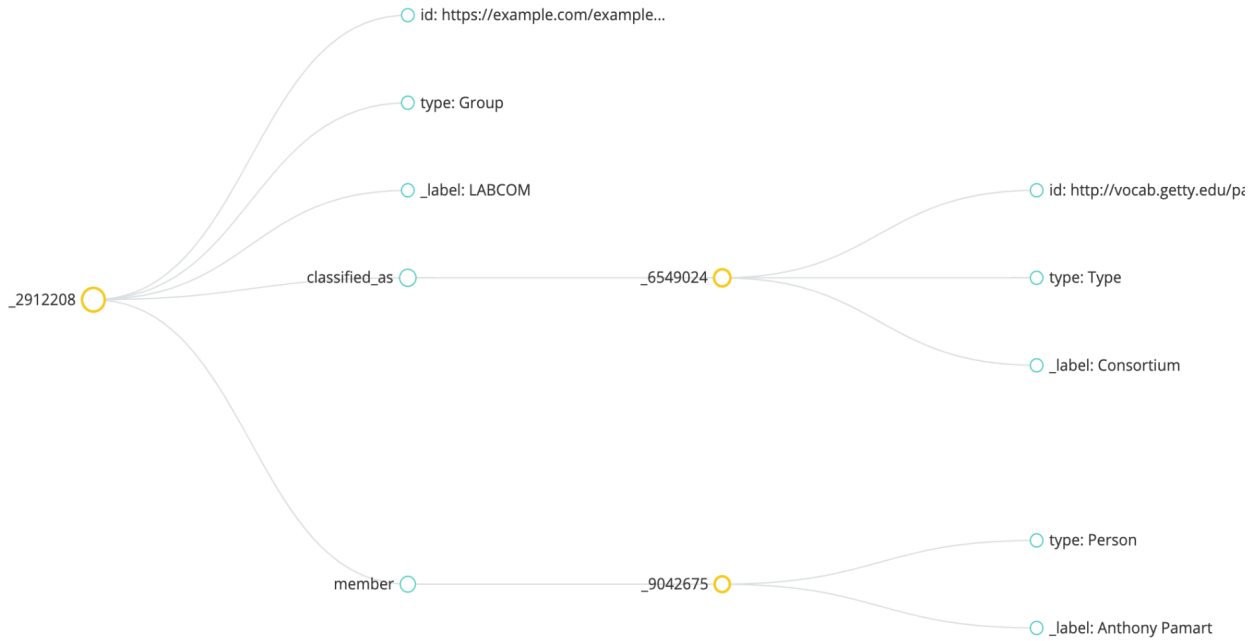

Figure 12. Example of web-semantic description of a who section serialized from a MEMoS JSON using Linked Art Data Model.

All the technical choices mentioned above (file format, verbosity, and metadata structure) have also been motivated to anticipate the utility of MEMoS descriptive documentation scheme toward web-

semantic friendly data. Alignments between MEMoS with FAIR and linked open data principles is already a work in progress. On one hand, our approach is freed from the constraining formalization of metadata input imposed by other standards. On the other hand, the supposed flexibility of the W7 model will also have to be evaluated with mapping and aligning procedures with a standardized metadata scheme (Dublin Core, others). This crucial open discussion about MEMoS' formalism and alignment with other standards, currently in preparatory phase, will be developed in future works. However, our approach is inspired by a wider CH oriented conceptual model developed in the past few years at different levels (acquisition, processing, annotation, etc.) to create and improve data provenance and semantically enriched digital documentation [Carboni et al 2016]. As a proof of concept, from the CIDOC-CRM based W7 mapping presented in Fig. 5 a trial has been made to derive MEMoS JSON contents into a web-semantic friendly format (see Fig.12).

6. CONCLUSIONS

In this paper, we have presented MEMoS as a system conceived and developed to improve data provenance and management CH multimodal digitization and digital documentation practices. Our proposal offers the possibility to include in the data-stream, meaningful and useful metadata or paradata that most of the CH knowledge domain and expertise would benefit from. A solution is proposed to exploit a versatile metadata enrichment inspired on the W7 ontological model directly integrated at capture time using 2D barcodes. By anticipating and automating metadata and paradata description, our system aims to contribute to a fluent transition of CH practices over data lifecycle renewal and toward the FAIRisation of CH data. The overview of CH-oriented data management solutions exposed the growing needs and expectations in term of interoperability to embrace the variety of tools and methods used by several expertise fields. In articulation with other tools, MEMoS could participate in increasing the value and the knowledge from current digital documentation crossed-practices. The technical implementation of our system, including software and hardware requirements, is currently at experimental phase but the possible and viable solutions presented aim to orient further development to reinforce user-friendly and versatile priorities. The illustrated case studies prove MEMoS' efficiency in variated and rich data acquisition contexts as its description schema can be adapted to different levels of DH projects. More globally, this work aims to contribute to DCH studies long term strategies by reinforcing the capitalization of knowledge and the reinvestment of experiences for further reuses.

In more prospective uses, we imagine that MEMoS will enable sense-making graphical descriptions of complex multimodal data sets exploiting InfoViz methods. Such interactive representations, if integrated or in dialog with 3D viewers, could also be enriched with a query system to create innovative ways to explore and help the interpretation of CH digital documentation. When a critical mass will be approached, future works will focus on harvesting and analysis methods to reveal the overlapping of modalities in correlation with semantic enriched spatialized annotations. Through these means, the goal is to derive from the concept of multi-modality to progressively deepen the notion of intermodality, understood as the combined and intentional use of multiple modalities for information carriers through digital contents.

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