Knowledge management for modelled Heritage objects, requirement specification towards a tool for heterogeneity embracing

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Abstract As information technologies gains common adoption in the humanities, cultural heritage study remains a special domain. Fundamentally interdisciplinary, cultural heritage works articulate several specific challenges: incompleteness, close link to documentation and the need for many domain collaborating. Modeling tools and methods have been under vibrant development in the past twenty years. But while a lot of efforts has been put towards overcoming practical issues, ethical and methodological issues nowadays require further advances. The *Reseed* project aims to bridge some gaps in the digital use for cultural heritage. This paper aims to shed light on the need to embrace heterogeneity with the aim to entrench model contextualized analysis. Currently in the process of developing fitting solutions, we present our partial implementation, which we supplement with more global requirement specifications. We base our proposal on a domain analysis and confine its scope within a critical discussion.

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1 Introduction

Digital tools for data retrieval and objects modeling reach, altering practices and professions, in an increasing number of domains, manufacturing production, building construction, health and medicine, etc. The cultural domain and more specifically the cultural heritage domain is not exempt of transformation. Additions of new tools aim to at least partially eliminate old limitations, being primarily, in cultural heritage, data interoperability [5](i.e. on one hand the capacity to share and link information between various services/institutions and on the second hand the capacity to share information structuring). The interoperability quest has found various incarnations: the development of data base languages, data models, generic and domain ontologies, in the development of dedicated programs and web interfaces for data linking. Practices maturing lead to strong effort towards unified conceptual modeling, and the development of a vast diversity of tools and formats. Many technical solutions have arisen but do not integrate two aspects : paradigm heterogeneity and ethical and methodological considerations. Within the ANR funded *Reseed* project, we aim to propose digital tools in order to ease the heritage working researcher's modeling integration possibilities. In the same time, we advocate for tool integrated modeling choices recording, and therefore propose in this paper specification requirements matching our needs. Section 2 presents the state of the art on modeling for digital heritage, and shows numerous efforts towards interoperability, completed in section 3 by our analysis of the remaining problems to tackle and their ethical foundations. From this analysis, we propose structured specification requirements, addressing these issues in section 4, and show its partial implementation in section 5. This paper ends up with a critical discussion on our proposal in section 6.

2 State of the art

2.1 Global panorama

Literary studies develop TEI approaches for text encoding and representation (e.g. in [16] or [18]), but also gazetteers [21] and geo-referenced data [9], as well as 3D modeling[13]. Fine art studies use image recognition techniques [37] and modeling in order to structure the knowledge on the objects [25]. Heritage objects and sites study and evaluation teams build up databases [24], and create informed 3D models in order to deploy BIM / PLM-like approaches [27]. In heritage conservation, digital tools have been more frequently used too, for displaying information, but for classification purposes as well [20]. Buildings diagnostics team use — among other digital forms — tomography [32] and multispectral imaging [10] in order for them to identify the pathologies that affect the buildings. Platforms appear for people to work, create data, analysis, and visualize results (3DHOP, Cyark, Sketchfab, Europeana, etc.). Private, public-funded, profit and non-profit initiatives cohabit. For 3D models, most platforms focus on making 3D data visible or accessible, but some try to integrate all of the heritage knowledge lifecycle [2].

2.2 Detailing the heterogeneities

All of the above listed forms of cultural heritage modeling face interoperability limitations, arising from heterogeneity. Visser et al. [39] distinguish 4 types of combining heterogeneity: paradigm heterogeneity, language heterogeneity, ontology heterogeneity and content heterogeneity. Paradigm heterogeneity covers a fundamentally structural aspect of modeling, the way we approach objects and system: object oriented databases, relational databases, discrete 3D modeling, boundary representation, document encoding,... The diversity of languages driving the modeling comes as the next source. Data base query languages, mark-up languages, horn-clause logic or production rules, for example. Now the type of modeling and the data operating language are not in question, but the data structuring, the logical relationship between elements. Ontologies and file data models bring their part of heterogeneity, which is then completed by the actual modeling activity where a same object could be designed by unlinked authority records or different descriptive geometries.

Such diversity makes it hard to interoperate data and models, but research fields about bridging heterogeneity gaps developed dedicated tools. Going through them all is pointless as there are so many of them, but with a few example we will be able to illustrate the trends in the efforts towards interoperability.

Content heterogeneity URI and generally semantic web technologies enable the unique designation of entities, reinforced by the creation of authority control systems [38]. In geometric modeling, identification and automated reconstruction tools for 2D and 3D modeling, as well as centralized components catalog help reduce content heterogeneity. TEI guidelines in order to share standardized content modeling has the same aim in text modeling.

Ontology heterogeneity has been mainly tackled by the creation of standard ontologies and conceptual reference models, but in practice, a lot of non-standard, domain-tailored ontology extensions are in use. Computational approaches, calculating similarities (lexical, semantic or geometric) help reduce this trend.

Language heterogeneity is more or less important, depending on the modeling paradigm. In text modeling, converting tools for XML to HTML have been developed [19], in 3D modeling B-rep and discrete modeling now have converting tools [11] and shared formats [28]. In database modeling bridges between query languages [36] and context adjusted data query systems have been created [40].

Paradigm heterogeneity has been faced through the use of linking interfaces, for example Culture 3D cloud or Aioli, for linking 3D geometric models, documentation and databases [2], [30]. More generally, the BIM / PLM / KLM approaches and their dedicated file formats (.ifc, .igs, .step,...) aim precisely to bridge this heterogeneity.

2.3 Domain ethical and methodological needs

These practical aspects enable model constructions and interoperability, but practitioners ethics and methodologies bring their own constraints. In cultural heritage works inherently have to deal with incomplete information and must handle indetermination, hypothesis and granularity choices. Systems and work interfaces managing these considerations have been developed in many domains, for example among others in architectural heritage [35]. Also, as the objects are unique and requires multiple source expertise, team work, and remote or virtual operation (manipulation, measurement,...) have been researched by cultural heritage practitionners [15].

Orbiting around each other, heritage works and tourism have a growing reciprocal influence [41]. There is clear competitiveness of countries to attract the most possible tourists [33] as well as the most possible funding from their guardian institutions. Digital heritage modeling for documentation, explanation or valorization purposes has grown with the number of sites and objects studied and recognized. New forms of heritage management evolved from the trend towards heritage tourism [17], and similarly, new practices arise from the digital incursion in heritage management [6], [7].

As one can expect, this very dense canvas Weavin cultural identity construction, significant financial stakes, competition and innovation, has become into a flourishing market as well as a fertile ground for research and academics.

However, the digital evolution pace also created skill gaps in the usual work process. A typical heritage service in a relevant institution ties close connections with archivists, librarians and photographers. Now it needs to create relationships to geomatics and reverse engineering professionals and information technology experts. Woven in a very organic way, through geographical nearness and chance, this new professional web builds an interface between practices.

3 Problem statement

3.1 Context

One of the origin key ambitions fueling the project was trying to beat the inherent limitations coming from digital use, necessitating specialized tools and fast evolving skills. For example, institutions rarely have digital teams with the necessary skills and resources to produce, manage and maintain dense points clouds or precisely facetted and textured meshes of their object, that could be useful in heritage research. Often opting for jerky outsourced and on-solicitation works instead of the continuous data production and maintenance that is granted to their other forms of documentation, the institutions need support in their digital data management, especially towards BIM / PLM / KLM approaches.

Precisely in this very teeming multi-layered research context emerged the *Reseed* project. Publicly funded by the ANR, the project gathers mechanical and industrial, data modeling and 3D data processing researchers, and heritage experts from the academia (namely University of Nantes, Centrale Nantes, the Technical University of Troyes and the Technical University of Compiègne) the industry (a software development company and a heritage consulting firm) and institutions (The Musée des Arts et Métiers, and the *Mission Inventaire général du Ministère de la Culture*), federated around methodological and operational questions on BIM/PLM/KLM approaches of heritage objects.

Specialized in science and technology heritage, our working group, chose two main case studies upon which tweaking, researching and testing. The first is a cultural landscape site, the Pic du Midi Observatory. Astronomical observatory located in the Pyrenees, the site hosts scientific and touristic activities for almost hundred and fifty years. The second use case is a series of Science and Technology objects, astronomical instruments called meridian circles. Built by the 19th century French maker Gautier, the seven instruments composing this series are spread through out of France (Paris, Marseille, Lyon, Hendaye, Besançon, Bordeaux and Toulouse).

The activities of the projects team varied from 3D scanning and modeling of today's state of the large observatory's site, 3D reverse engineering of past states based on the documentation, archival work and the constitution and consultation of databases. We developed a draft prototype for the Pic du Midi Observatory [14], [22]. And built a database linked to digital documentation with a CMS (namely omeka s), in order to produce data visualizations [8].

From our experience, incompletion, hypothesis, possibly divergent yet combined points of view and documentation integrity conservation are the key domain constraints to integrate in digital tools for heritage. But foremost, it seems that *cohabitation*, *linking* and *exegesis* of heterogeneous models is a fundamental methodological need in cultural heritage research.

3.2 Reasons for modeling cohabitation, linking and exegesis

By modeling cohabitation, we specifically mean keeping the heterogeneity as it is in original models, and adding a translated version in order to achieve interoperability without altering diversity or original model integrity. The previous tools focus on translating to remove or lessen the heterogeneity. We argue that the keeping information about the heterogeneity is actually a great source of needed information in a cultural heritage context.

3.2.1 Understanding the modeling background

The interdisciplinarity claimed in digital heritage approaches results in the merge of two or more practices, often tools and skills from one discipline are tweaked and used in another. Fore heritage documentation, the tools often originate from another discipline working on data production. LiDAR scanners come from the world of geomatics, topography and metrology, resulting in various scanners brands, types, designed for specific scales and types of objects, as well as specific applications [1]. BIM software used for documenting heritage buildings come from the construction industry [31], and are tweaked in order to manage hypothetical, uncertain and incomplete data. In a similar way, heritage studies deploy reverse engineering methodology and tools from industrial and mechanical engineers [26]. All of those approaches create a specific type of interdisciplinarity. LiDAR scanning produces point clouds faceted or not (.pts/.lsr/.e57), BIM and reverse-engineering approaches results in software related or interoperable file formats (.rvt, .dwg, .cat*, .step, .stl). The several formats indirectly reflect the several types of interdisciplinarity.

In short, practice diversity creates practice communities, with different modeling techniques and formalisms. Without standardizing the intentionally diverse approaches, there is a need for a tool in order to share, gather and assemble the models (geometric or conceptual).

3.2.2 What we can do for fame

As stated earlier, heritage has a significant impact on the tourism activity, and tourism can be a substantial part of a country's economic growth [3], the temptation for embellishment of the authenticity or the integrity of the site, in order to present it more remarkable has been observed [12]. In order to enable a sound discussion and possible evaluation, heritage modeling choices needs critical approach, in order to contextualize information and documentation. Heritage modeling must be deployed through open technology, giving access to sources and modeling choices.

3.2.3 Digital documentation is dynamic

Digital documentation durability conversely to standard documentation only exists through continuous use of the data [4]: allowing for the creation of copies, possibly converted into new formats. Documentation in a digital paradigm only lasts when accessible and usable, or more precisely, when accessed and used. Heritage explanation and valorization relies heavily on documentation, but further processes it into synthetic data integrated into visualization or narratives. The workflow from documentation, analyzed and then synthesized for the production of new condensed documentation doesn't change in digital framework. Heritage studies therefore need tools for easily transferrable data from one document to another, and thus explicit data format as well as technologies and strategies to ease data sharing.

4 Proposal as requirement specification

Reflecting the problem statement, the requirement specification we hereby develop corresponding requirement specification towards the creation of a digital tool corresponding to heritage modeling according to our analysis.

4.1 Modular data models and data sources

Although durability is most appreciated, evolution of the data models seems unavoidable with ontologists continuously improving their meta-models and domain concepts evolving with time [29] [42]. Furthermore, one could hope that data will only grow in number and in quality with time, and the heritage modeling should be able to be updated easily with relevant new information. The data and data model management should be explicit and contextualized by providing creation data/data model source, authority maintaining institution, and relevant meta data (date and user deciding its integration). Data update and completion should impact the whole workflow. If possible, even the new synthetic documents could be flexible enough to manifest the data modularity.

4.2 Tracking information and operations

Modeling, remodeling, data analysis and classifications tasks can be manual, directly performed by users or automated, run by a program. The needed critical approach on the modeling process and choices requires these information creations, alterations, aggregations, compilations, etc. to be recorded and accessible. Meta data creation mechanisms in order to record the context of the operations must be in place along the modeling workflow to enable any later user to be able to understand the modeling choices and operations performed while creating early works.

4.3 Identifying each information

Extending the previous point, tracking should be achieved at the lowest information level possible. Not only digital files and databases should be referenced, but each information used in a later operation should be tracked, and designed specifically in order to enable precise forward modeling as well as critical approaches for continuous improvement.

4.4 Importing data from any file type

File diversity resulting in data model diversity should not restrain. Interoperability and open sourced data models and file specifications should be the first priority in the implementation, but in order to cover the most possible modeling panorama, could be later completed by closed file formats and specific or niche data models.

4.5 Technical solutions

Globally, we propose to use and tweak semantic web technologies to implement our proposal. Although we still are currently working on a complete construction, we yet only have cumulative partial realizations, that we be presented in the next section. This section will present the principles of the implementation.

4.5.1 Data alignment and distance computing

Two types of data diversity that need management, lexical and logical, calling for different answers classically managed by ontology-based systems through schema alignment. Yet, as the modeling diversity also reflects modeling habits or intentions, and as we desire to track information alteration in context and as we want to be able to investigate hypothesis, we need a graph distance computing step prior to the potential alignment. In other words, alignment should never disappear in data model evolution.

Several techniques exist in for concept or entities alignment (cross modeling culture or languages), by graph structure or attributes embedding analysis, for example, and their modular implementation should help the user decide.

For less defined modeling techniques, semantic similarity based on lexical distance computing could be implemented as a complement to help for the data model exegesis. The approaches differ from one language to the other, in French the successive works of Ploux, Manguin and Morel ended in the very actively maintained

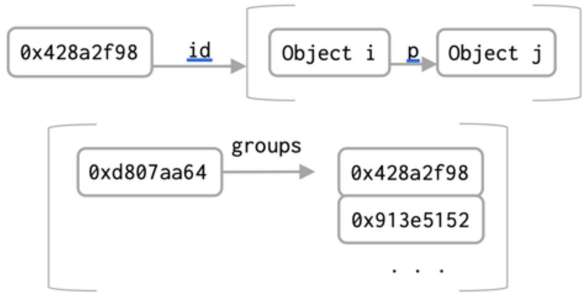

Fig. 1 Schematization of the use of NQUADS for individual and bundle data identification

Digital Synonyms Dictionnary (Dictionnaire Electronique des synonymes, DES in short) which could be a good synonymy solver module.

4.5.2 Data unique identification and change tracking

We propose following use of named-graphs and hashing in order to track every information at the lowest granularity level.

The ability to identify each RDF Triple calls for a unique name of them. We process each RDF Triple using a hashing function to obtain a unique name, that can later be used as fourth component when transforming the triples into NQUADS. The triple store contains mainly very small named graphs containing only one triple, as shown in the Figure 1. They can also be regrouped in bigger named graphs when there is a need for identifying sub datasets.

This mechanism allows for efficient data deduplication, only limited by vocabulary heterogeneity and precise tracking of modeling, for example to highlight:

- if a triple or a subset is reused across different models,
- conversely, they have been through any modification.

The capacity to pinpoint each triple, also enables thorough meta-data management, at single ou grouped information level.

5 Part implementation examples

In the course of the Reseed project, only partial development of this vast program has been conducted in order to test its implementation and ease of use.

5.1 Unconstrained and open-ended data modeling

In modular data model management, onus is on the user to decide. Much more responsibility doesn't imply a

Fig. 2 Data entry interface with schema choice

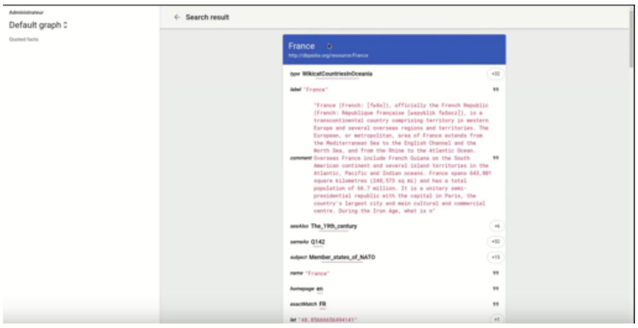

Fig. 3 External data request example

more difficult manipulation. In this sense, we produced a data entry interface, shown in Figure 2, easing the schema choice, developed in Kotlin upon the Jena and Spring libraries.

This interface also tackles modular data source. With the possibility to specify SPARQL Endpoints, querying on the local database also relays query to chosen data bases. For example, the Figure 3 shows a query made with our interface requesting dbpedia.

With this ability to operate on local data and data models as well as using reference databases and data models, combining modelling flexibility with possible interoperability is achieved.

5.2 Tracking information from source files final data visualization

In another implementation, we wanted to see what was possible at the time in order to track information from files, to a host database sheltering any type of data: unstructured text, structured data, 2D or 3D geometric data, ... In this regard, first, we manually extracted information from mostly text files, scans of archives, in order to produce condensed cards and then specific data visualizations.

For this implementation, we modeled a series of meridian circles, main astronomical instruments for astrometry for a century, between mid 19th, until mid 20th century. This instrument is actually composed of

Fig. 4 Meridian Circle of the Jolimont Observatory

two previously separately used instruments: a refracting telescope and a graduated circle. Combining two measurements into one instrument, meridian circles made the time and precision positioning on earth and in the sky for more than a century. A single maker produced all of the instruments of our series, and all of the telescopes are located in one of seven observatories across France mainland.

Our aim was to track and explicit technological evolutions throughout the rough hundred years of scientific use of the objects. We decided to use a robust existing CMS, omeka-s, for our data management testing.

With the data extracted from the documentation, we produced a generic describing card of each instruments (for example for the Parisian meridian circle, in Figure 5), as well as synthesis cards about people working with meridian circles (as shown in Figure 6) and about the actual operations the instrument went through, at macro level and at component level (Figure 5, 7 and 8).

From these data collections, we were able to produce data visualization easing the access to several layers of

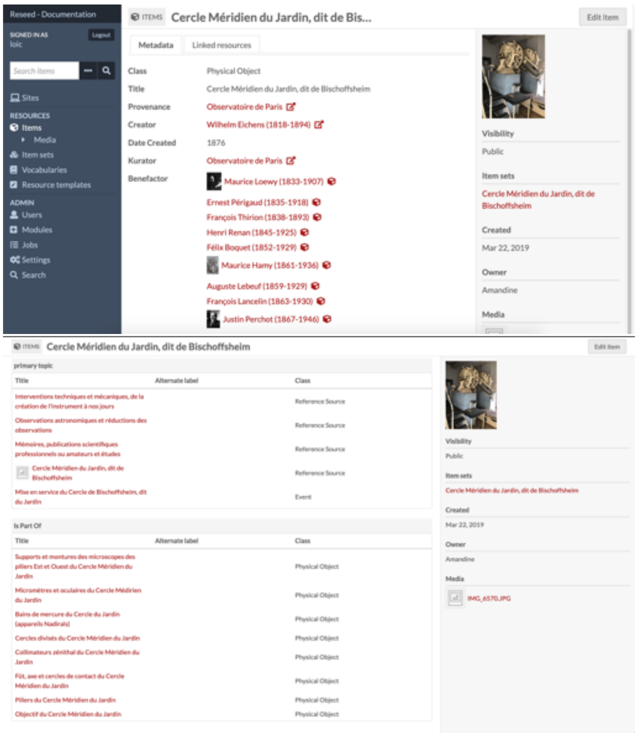

Fig. 5 Generic describing cards of the Paris meridian circle (also called Bischhoffsheim circle). Top: synthetic view. Bottom: focus on its components and the various activities involving the instrument

Fig. 6 Describing card of Guillaume Bigourdan

Fig. 7 Change record of the Parisian meridian circle's micrometers and eyepiece

Fig. 8 Change record of the Parisian meridian circle's angle measuring micrometers

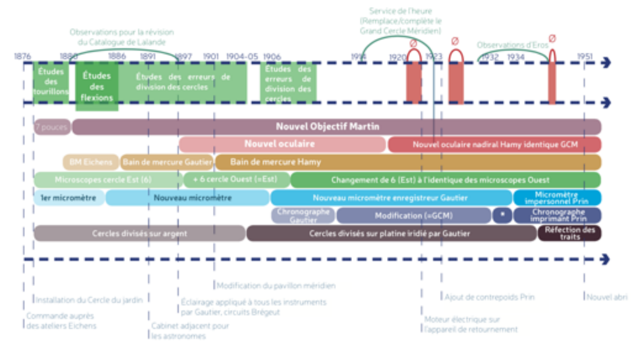

Fig. 9 Overall historical timeline of the Parisian meridian circle's part change and upgrades

information, giving a more concise view of the objet's evolution through time, presented in Figure 9.

Such data visualization eases further information connection and discovery and helps the formulation of hypothesis. It also eases collaborative works for it gives a common view of the data and entities.

5.3 Indexing information on a 3D model

In pursuit of this implementation, we wanted to test more diverse type of data integrating 3D data. First, we had to model the meridian circles. As the aim was the documentation of the object, we limited ourselves with capturing the geometries. We decided at this point to delay any possible reverse-engineering 3D by hand modeling, to keep independent from file formats and limit 3D data to colored spacialized points.

Linking 3D points to further documentation, we were able to index information on a visual representation of the object. The bottom part of Figure 10 shows a 3D point cloud from the visualization interface. 3 colored icons positioning further information sources can be seen in this figure.

By clicking on the icons, other visualization angle and documents are accessible, deepening the objects exploration (as shown in Figure 11)

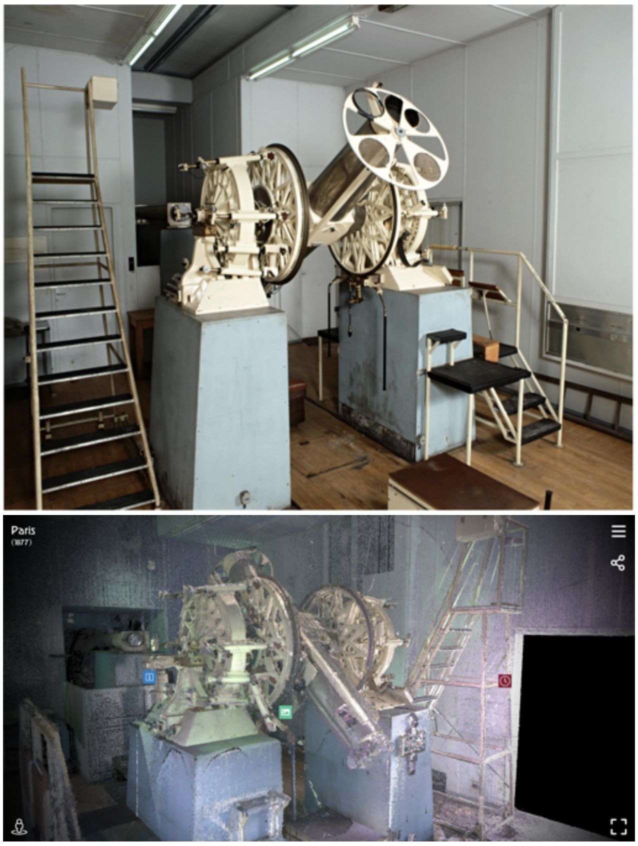

Fig. 10 Comparison between a picture (top) and a point cloud (bottom) of the Parisian meridian circle

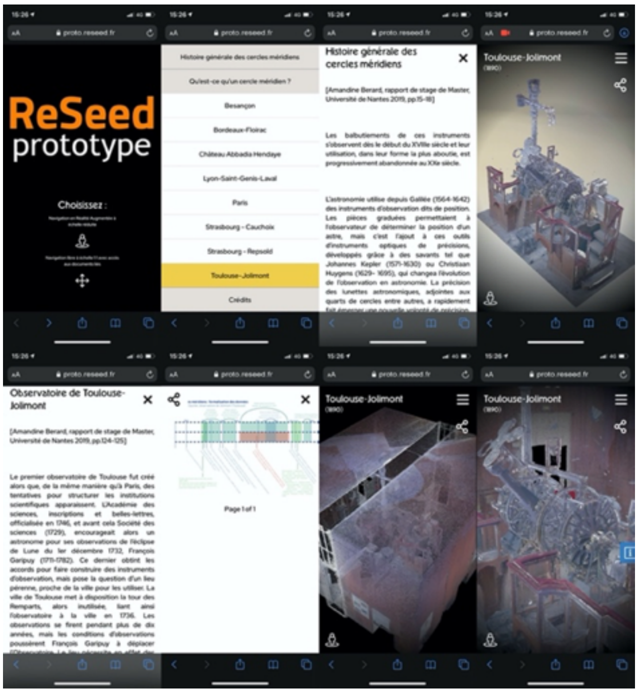

Fig. 11 Split view between informations sources

6 Critical discussion

One of our premises was that cultural institution had no dedicated team to face the heterogeneity limitations. It seems with time, this assumption might not stand as strong since institutions develop internally autonomous digital teams. The best example for this digital integration, and probably the yet most advanced institution in terms of research and operation organism is Historic Environment Scotland, where the digital team works transversally with all the other research teams[34].

A more elaborate version of this prototype merging all of the individual initiative is still missing, but the several explorative developments comfort us in the domain relevance of such a diverse data association tool.

Linking data and data source with relevant positioning on a 3D point clouds model also has been possible opening the way for modeling sharing CAD and point clouds object representations.

Getting rid of the approaches purely based on several files management without severing the integrity chain from physical document to data in a database led to new knowledge production [23] and confirms the relevance of our methodology.

Our approach is nevertheless not exempt of possible limitations. First by merging all relevant data (geometry, text, databases), we take the risk of ending up with a bulky dataset, and therefore we anticipated unique identification tools and deduplication mechanisms. Also, the assistance provided by the tool revolves around data presentation. Ultimately, the user is responsible for the structuring. Far away from being a drawback it seems for us the only way to end up with as rich as possible models. Yet the user has to decide for himself along the way and the data heterogeneity produced should be. Although, we identified tracks to start this aspect and aim to end up with semi-automated support, we did not start any actual work on this heterogeneity mediation. Further efforts need to be performed in this direction.

7 Conclusion

After presenting a diversity of approaches in modeling for cultural heritage, we analyzed the expression of various forms of heterogeneity and the practical answers modeling communities have developed. We then clarified the limit to the heterogeneity management with regard to the domain practices. The long time collaborative works and the hypothesis integration were our principal guides towards formulating specification requirements for a heterogeneity embracing tool integrating heritage modeling in its various forms. Finally, we presented the partial developments our project group developed, upon which we plan to build a more global tool.

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