

# Digital Documentation of the Reconstruction of Notre Dame De Paris

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## ABSTRACT

This paper demonstrates how digital documentation projects support engagement, analysis and interpretation of the reconstruction of Notre Dame de Paris, as well as demonstrating the underpinning processes by which the documentation itself is generated and managed. The digital documentation project is the scientific website which forms a digital ecosystem to support the reconstruction project, the reuse of the datasets is analysed in the original heritage discipline and across other disciplines by the OAIS reference model. Then, critically consider the main challenges to be for this project and how they are addressed.

## KEYWORDS

Digital documentation; Notre Dame de Paris; Digitizing heritage

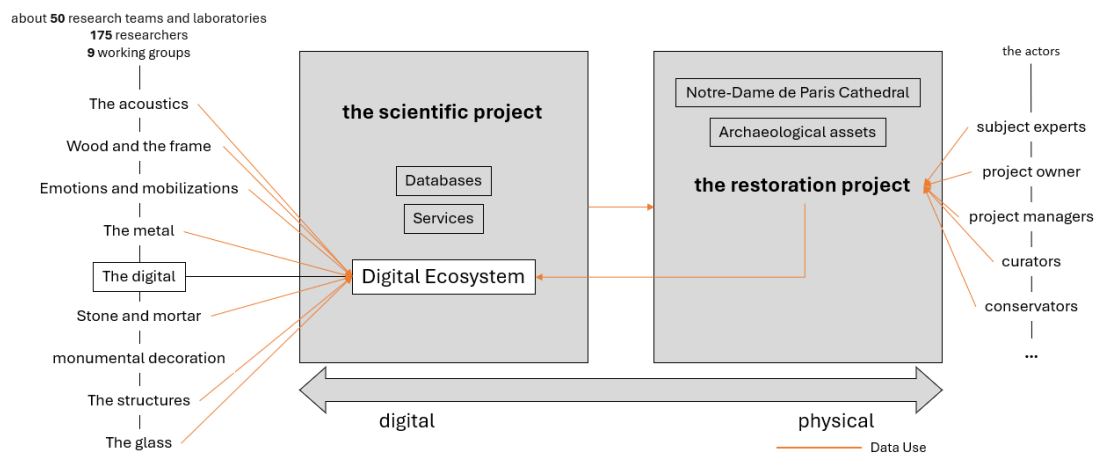
## 1. INTRODUCTION TO DIGITAL DOCUMENTS

A fire broke out at Notre Dame Cathedral in Paris on April 15, 2019. The spire collapsed on the last two spans of the nave and most of the timber roof was gone above the vaulted ceilings.[1] People mobilized like never before and began building a massive repair system. By mobilizing donations from individuals, businesses and communities worldwide, a national donation was established in September 2019. The funds will be used for conservation and restoration work and the training of relevant personnel. On July 29, 2019, the Notre Dame Cathedral Restoration and Protection Act was adopted to ensure the implementation of the project. A public administration agency was established on December 1, 2019, and an official website[2] for the release of restoration project information was established. An assessment study was conducted in June 2020 to develop an overall health assessment of the building and determine the direction of the restoration project.

The day after the fire broke out, the French Ministry of Culture and the National Center for Scientific Research (CNRS) launched a huge restoration and scientific research project in parallel with the restoration project[3]. The two projects support each other and have multiple overlapping aspects of research questions and research teams. The scientific project brings together researchers and laboratories from across France and is coordinated by Martine Regert (CNRS), Aline Magnien (MC), Philippe Dillmann (CNRS) and Pascal Liévaux (MC), setting up nine topics including the "Digital Group" Working Group[4].

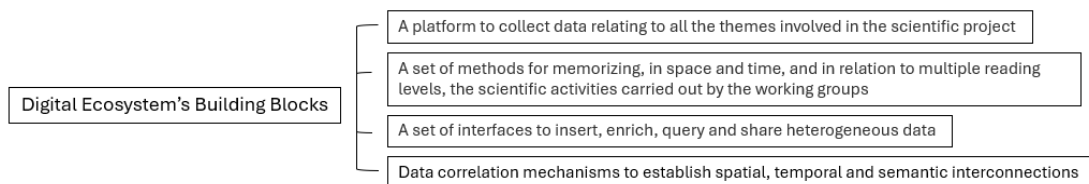
The project aims to establish the cathedral's digital ecosystem, creating a database that will be continuously updated as the restoration project progresses, while also providing data services. In terms of the use of data, nine working groups participating in scientific projects upload data information to the data storage center at any time, forming the basis of the digital ecosystem. The data in the system is also open to restoration projects. For two major cross-cutting projects, one is the restoration of wooden roofs, involving materials (wood, metal), architecture, and mechanics; the other

is the restoration of vaults, involving materials (stone, metal), archeology, architecture (composition, geometry) and the study of structural behavior and intangibles acoustic and traditional emotions[5], prosthetic groups and digital groups collaborate to generate data that is fed back into the system. (Figure 1)



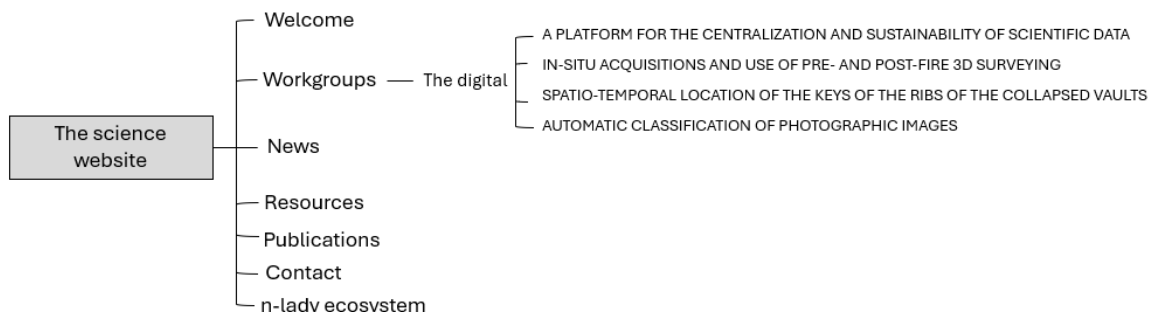
**Figure 1.** The structure of projects and how data is used between the scientific and restoration project

This work focuses on the exploration, analysis and enrichment of a corpus of images and annotations of the cathedral, about their temporal, spatial and semantic aspects, in addition to their visual content..[6] Digital ecosystems can be described as four building blocks. (Figure 2)



**Figure 2.** The structure of digital ecosystems, sourced from the science website[[7]]

The most important online resource for this scientific project is the scientific project website[7] provided by the French Ministry of Culture and the CNRS. The website has seven navigation bars. (Figure 3) The information provided by the website has good project extensibility, providing a communication and tracking channel for professionals and ordinary audiences.



**Figure 3.** The structure of a science project website

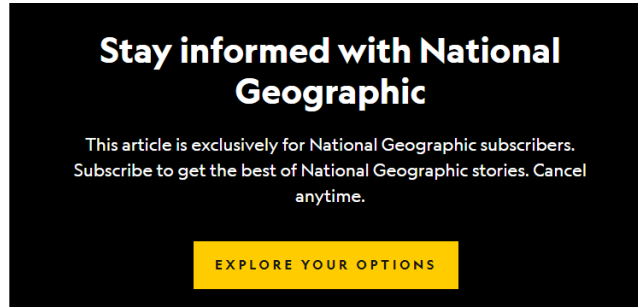
Lectures, conferences, documentaries, social media, magazines, etc. associated with the project can be easily found in the "News" and "Resources" sections, including videos, pictures, and jump links. The "Publications" section not only provides project-related journal articles and CONFERENCE POSTER, but also provides retrieval entrances for three types of metadata: Authors, Year of

production, and Laboratories. In the "Contact" section, the website provides the contact email for the scientific project.

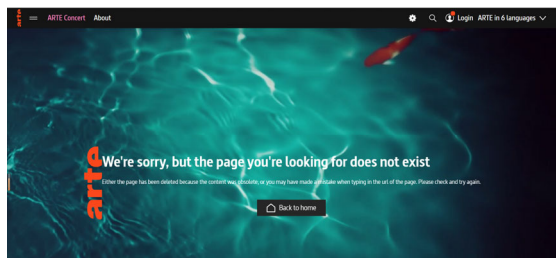
However, not all of these online resources are open access. For example, the website displays information graphics that appear in National Geographic (Figure 4.1) but requires a subscription to have reading permission (Figure 4.2). There are also some broken links. (Figure 5.1) Broken links illustrate the potential risk of incomplete data. However, some links are not really broken, because they can still be displayed normally through Google search, but they will be invalid if you click directly, which may be related to the lack of timely maintenance of the website. The "n-lady ecosystem" section requires work identification to be viewed. (Figure 5.2)



**Figure 4.1.** Screenshot of the website showing a chart that appeared in National Geographic magazine



**Figure 4.2.** Screenshot without access to National Geographic magazine



Le fichier souhaité n'est plus disponible!

**Figure 5.1.** Screenshots of broken links

**Figure 5.2.** Screenshot of membership authentication

Digital technologies play a role in multiple working groups on scientific projects. For example, the acoustic team collaborated with the digital team to reconstruct the acoustic experience of the cathedral. Next, I will introduce the "Digital Group" of the "Work Team" section of the website in detail. The "Digital Data" working group, coordinated by Mr. Livio de Luca (UMR MAP), brings together members of [12] research units.[[7]]The main work of the Digital Group is to establish a digital ecosystem based on scientific projects. To build and provide this information system, the "Digital Data" working group carries out activities around four complementary aspects: collection and integration of existing digital data; development of new data generation; long-term sharing and archiving of data; structural and semantic enrichment of data. Specific work carried out includes a platform for scientific data centralization and sustainability; on-site collection and utilization of pre-fire and post-fire 3D surveys; spatiotemporal identification of collapsed vault rib keys; and automatic classification of photographic images. The platform also includes the implicit goal of creating a kind of "digital memory of a collective endeavour", whose content would be accessible and reusable under the FAIR principles as an emblematic example of scientific heritage data.[[8]]

To build this digital ecosystem, the digital technologies used are:

- A digital twin-driven approach within the framework of architectural heritage restoration, applied to the reconstruction of the collapsed part of the nave and the restoration of the vaulted ceiling, developed from four steps: physical anastylosis, reverse engineering, spatiotemporal annotation of remains, and operational research[1]. The advantage of this is that it provides virtual, replicated, updated data, and the workflow is very flexible because it can work as parts.
- 3D laser scanning is used to compare the state of the building before and after the fire to analyze the damage state of the building after the fire. It is necessary to use this technology, the curvature of the vaults cannot be measured by hand. Similarly, the scan captures the inside of the roof. That roof had been measured, there are drawings of the roof but nothing as complete and accurate as the scan[9]. The 3D point cloud is used along with pictures (2D data) obtained by photogrammetry, which also serves as a method for vault restoration. Both methods have benefited from essential functionalities offered by two open-source solutions proven to enable "real-based" modelling in Cultural Heritage contexts, namely Micmac and CloudCompare.[10]
- Use the generic CIDOC-CRM and its digital extension, CRMdig, to build the data model.[6]
- Remote sensing, QR tags, and sensors are been used to connect physical and digital assets. Remote sensing via both TLS and photogrammetric surveys produces the compulsory geometric representation layer of the built asset and its disbanded parts. [1] The need to go back and forth between the physical asset and its digital surrogate pushed for the use of QR code external tags for the voussoirs that complement the metadata links in the inventories. [1]

The project outcomes include:

- Dataset: Data already collected (and partially documented) from cultural institutions, research laboratories, and private companies include (i) 180 000 photographs (before and after fire, during the restoration); (ii) 5000 3D point clouds (before and after fire, during the restoration); (iii)

hundreds of technical drawings (before fire); (iv) dozens of structured 3D models relating to the cathedral's condition before and after the fire; (v) 5000 documentary sources (archives, bibliography, iconography) relating to the cathedral's history. [[5]]

- Databases: The platform provides website tools that serve different purposes, from data storage to data sharing. The third-party platform it cooperates with is shown in Figure 6.
- Services (Figure 7) Figure 8 is the content posted by the restoration project's social media account as part of the data disclosure service.

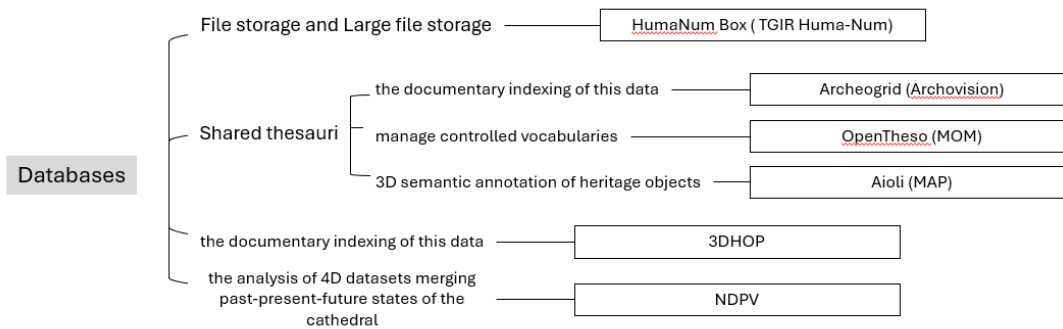


Figure 6. Web services provided by HumaNum platform

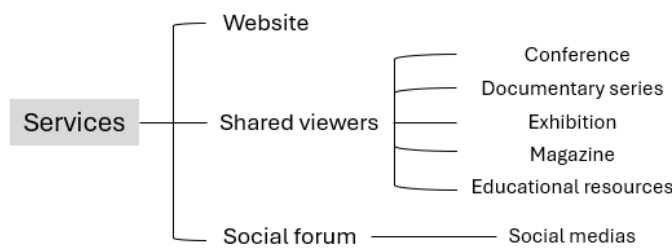


Figure 7. Data services provided as project outcome

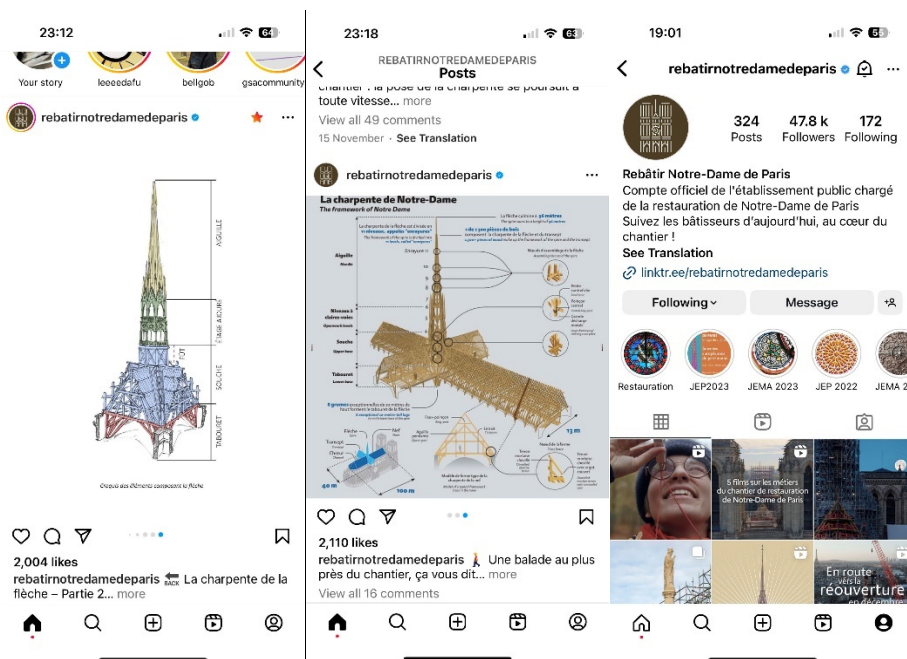


Figure 8. Screenshot of the repair project social account

This is a digital project in parallel with the restoration project, and the entity that needs to be created has disappeared. The restoration of the entity relies on the data set, so the data set first inspired the heritage field to rethink the interaction between digital and physical assets are stronger. For example, in the restoration of stone arches, after the digital reconstruction is completed, stone cutting and sensor monitoring for physical reconstruction also need to be considered.

The reconstruction of Notre Dame reflects more deeply the duality of heritage: historical and contemporary, with the effort put into restoration projects representing its historicity, while the investment in digital projects represents The care that heritage can bring to contemporary society. Facing an ongoing project, I was allowed to watch its restoration progress, an experience that transcended space. At the same time, my actions form part of the continuously updated data of the digital platform, and I become a member of the digital community. The platform also includes the implicit goal of creating a kind of “digital memory of a collective endeavour”, whose content would be accessible and reusable under the FAIR principles as an emblematic example of scientific heritage data.[[8]] Beyond the mere physical phenomenon, the subjective perception of the acoustics of a space constitutes a real heritage value that must be documented and archived.[[11]] The acoustic model was generated from the testimonies of people who had previously used cathedral sound, which I think emphasizes the importance of human involvement in digital community building.

Data management principles based on the FAIR principle show us the beautiful vision of long-term sharing of scientific platforms, to provide the scientific community with a generalizable approach, a reproducible methodology and an open and reusable digital ecosystem to build cathedrals of multidisciplinary data and knowledge through collaborative research on material objects [[12]]. But now, the platform’s data is only available to researchers. I divided the information in the dataset into "specific" and "general", with specific information being used in heritage and related research areas, such as digital twin applications, which are further related to the construction, manufacturing and aerospace industries. However, it is undeniable that the use of heritage data has limitations, as Cultural Heritage objects are unique by definition, the methods, the practices and the strategies to build digital documentation are not homogeneous, universal or standardized[[13]].

General information can be found in any field of possible use. 3D models are an example. After the fire, the digital modeling of Notre Dame de Paris was based on the game Assassin's Creed, precisely because the three-dimensional model can serve as a kind of universal digital information. Therefore, the data produced in the heritage field has the potential to promote the development of entertainment, education, and medical industries. Also, different people look at the same data set from different perspectives. Architects, archaeologists, and chemists can inspire each other and generate new data analysis perspectives, this also illustrates the importance of establishing a cross-professional thesaurus. In particular the use of mappings and common vocabularies in the context of a knowledge graph in Linked Open Data (LOD).[[14]] This process can be described as weaving together the links between heterogeneous and impermeable datasets[[15]].

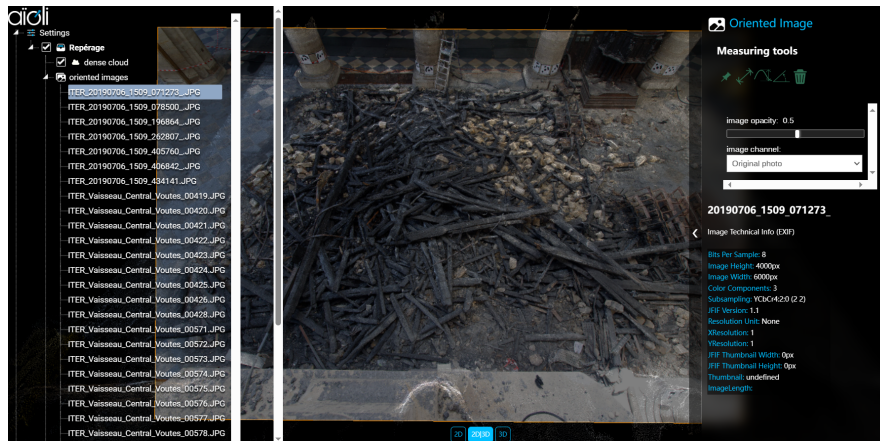
## **2. INTRODUCTION TO PROJECT DATA**

### **2.1. Metadata and Thesaurus**

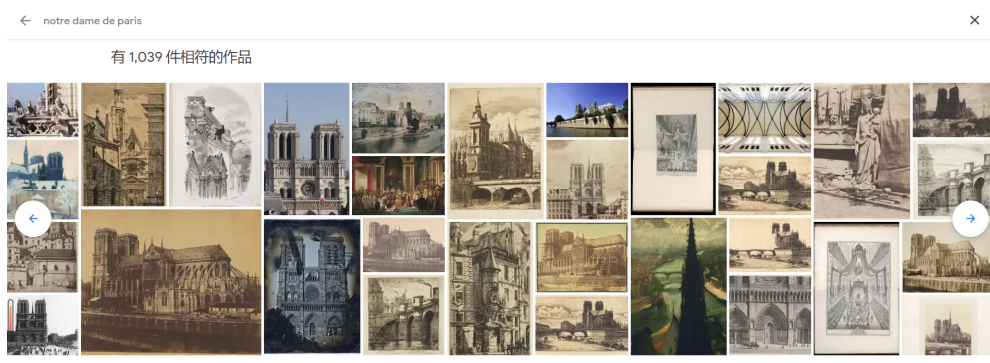
For this project, HumaNum Box stipulates that the SIP must contain 5 mandatory metadata sets (nakala:title, nakala:created, nakala:type, nakala:license and nakala:creator)[[16]]. AIP must contain: perennial identifier (DOI), file fingerprint (SHA1), submission date, file sizes, file names, producer identifier, format identifier, management rules (type of data, final destination, retention period, communicability)[[16]].

I think the collection and automatic indexing of photos is crucial in this project, their visual content is as relevant as the spatial, temporal, and semantic dimensions expressed through the joint use of

heterogeneous forms of metadata. [[17]]The collection of photo resources about Notre Dame can be found in the media library of the Ministry of Culture[[18]], the database of the Ministry of Culture[[19]], MPP[[20]]. Aioli is a platform for semantic annotation of 3D images. Picture resources are also used here. These photos of the same object in different periods are continuously superimposed to complete the researcher's understanding of the architecture. I think metadata such as who made the photo, basic description, survey type, location coordinates, etc. could be supplemented in this website. (Figure 9) The metadata recording the photos of Notre Dame de Paris can also be used on derivative platforms, such as Google Culture and Arts. (Figure 10)

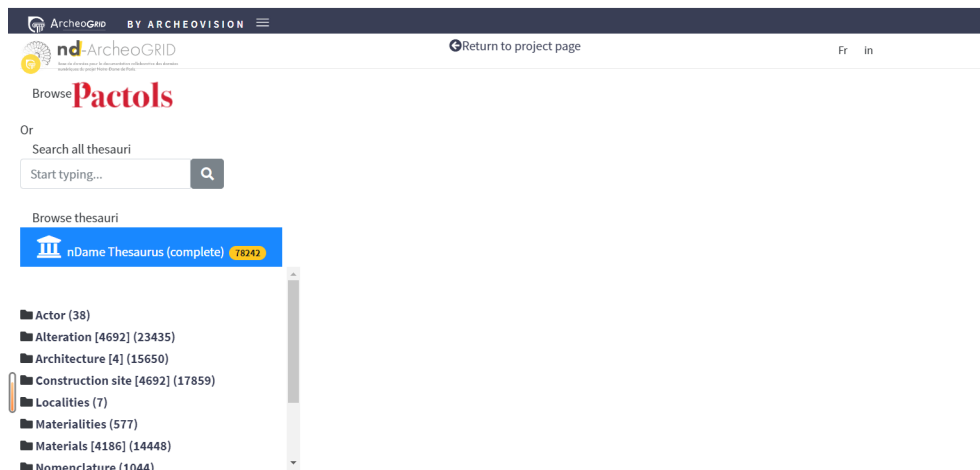


**Figure 9.** Screenshot of use of photos and photo information on the Aioli platform



**Figure 10.** Screenshot of Images of Notre Dame from Google Arts & Culture

In this project, the thesaurus generation and management platform is OpenTheso, but thesaurus can also be found on the data indexing website Archovision. The project's thesaurus has a total of 78,242 words, including categories such as architecture, materials, sculptures, and implementation techniques. (Figure 11) Thesauruses have a general purpose of enhancing metadata at any level and can also help automate the spatio-temporal annotation and identification of artefacts in a single processing chain[[1]].



**Figure 11.** The thesaurus published on Archovision

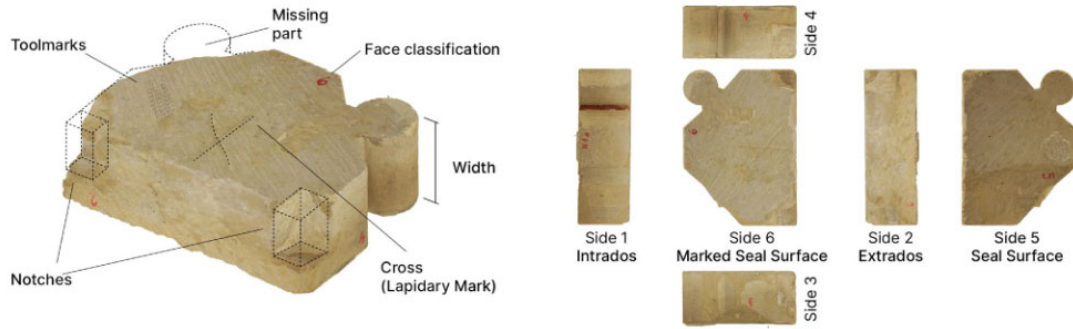
## 2.2. Paradata and London Charter

Preliminary work has proposed the term paradata to describe the unique documentation needs that emerge for archivists using AI tools to process records in their collections.[[21]] Compared with metadata, paradata is a kind of process data that explains every data change. The science group emphasized building semantically rich data corpora: a data enrichment process that not only describes digital assets through traditional metadata, but also stores the different steps scientists take from raw data to interpretation and knowledge.[[5]] This shows that this project uses paradata. For example, the spatial information is a transversal component across the metadata and paradata collection in the datasets about Notre-Dame.[[22]] The Aioli platform also uses paradata. (Figure 9)

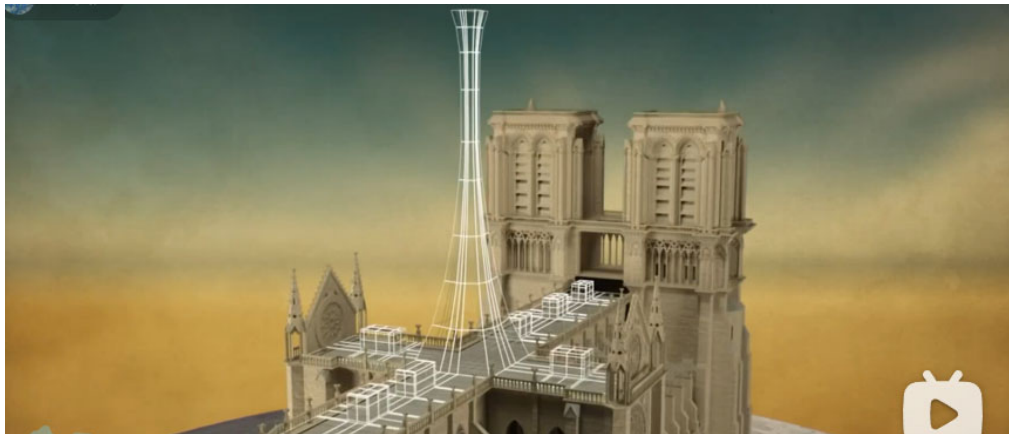
The London Charter[[23]] recommends designing a strategy for recording materials, managing materials and making them public; publishing recorded materials should use the most effective alternative media and use sustainable media materials. The London Charter also advocates transparency in the use of 3D models in cultural heritage[[1]]. The type of information required is a 3D model, which can be used to:

- restructuring existing but dismembered part in a virtual model[1], such as vault remains fragments. (Figure 12)
- An attempt at the steeple plan. (Figure 13)
- Post-disaster assessment. (Figure 14)
- Media usage. (Figure 15.1&15.2)

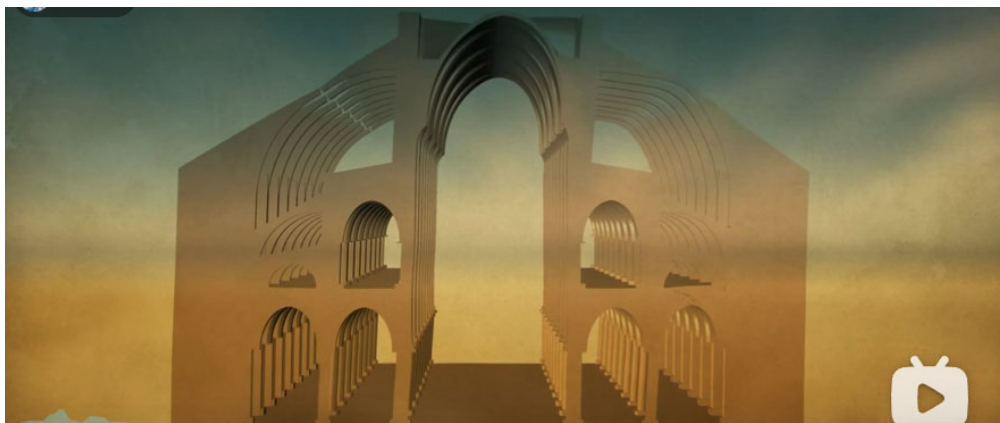
In addition, information types such as: citizen surveys, multi-scale (from architecture to remains) 3D digitizations based on laser scanning, photogrammetry and RTI (Reflectance Transformation Imaging), 3D reconstructions of hypothetical states[[5]], would also help to implement the recommendations of the London Charter.



**Figure 12.** The components of the collapsed arch: the voussoirs, standardized and manufactured building elements. [[1]]



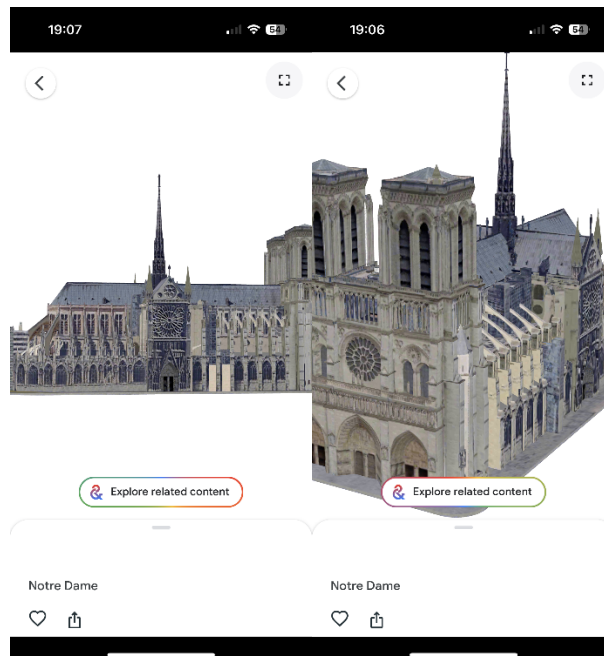
**Figure 13.** Try out various minaret design options using 3D modelling [错误!未找到引用源。]



**Figure 14.** Calculate the bearing capacity of the tower top using 3D modeling [错误!未找到引用源。]



**Figure 15.1** Visuals were produced from captures of the interactive visualization environment of the 3D data of the cathedral from the “digital data” working group, produced by Roxane Roussel. National Geography.



**Figure 15.2** Google Arts & Culture uses 3D model to introduce Notre Dame Cathedral

### 2.3. OAIS

The three information packages of OAIS are Submission Information Package, Archival Information Package and Dissemination Information Package. The archive generator uses SIP to submit it to the archive collector. The archive collector organizes the information, creates AIP for long-term preservation, and then uses DIP Distributed to file users. The metadata contained in SIP generally uses XML format. Since the storage location of AIP is a collection of all SIPs, AIP will have more categories in the folder classification, such as year and version, each year or each version contains all corresponding SIPs. AIP has the characteristics of long-term preservation, so multiple sets of backups need to be made, which may require different electronic file formats and different storage devices. AIP also bears the responsibility of generating DIP. In order to facilitate the distribution of files, the ZIP format is often used. Compared with AIP, DIP has less content and does not need to save all versions, so the number of folders and ZIP files is smaller. In order to meet the needs of file users who use various devices to open DIP and the information remains accurate, some text files need to be in PDF format, image files can be in SVG format, and 3D models can be in PLY format.

### 3. SUMMARIZE

The restoration of Notre Dame de Paris was built on ruins, which reconstruction is necessary. In addition to its national symbol, tourism and landscape significance, the entire restoration project also demonstrates the ethical significance of heritage protection, such as respect for the burned wooden roof and the requirement for materials. And craftsmanship is highly restored rather than directly adopting easily realized modern architectural structures. The tremendous efforts made by everyone in this event are the best embodiment of the pursuit of heritage authenticity. The fire at Notre Dame de Paris, the fire at the Mackintosh Library, and the fire at the National Museum in Rio de Janeiro have different cultural backgrounds and historical statuses, but each disaster prompts us to think about the generation of emotions about heritage and take measures to preserve or restore it. No experience in the restoration of one property can be completely replicated on another, which is evidence of the rich significance of the heritage. But no matter what, digital forces that cannot be ignored will push heritage into a more eternal future.

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