The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVI-2/W1-2022
9th Intl. Workshop 3D-ARCH "3D Virtual Reconstruction and Visualization of Complex Architectures", 2–4 March 2022, Mantua, Italy

BIM APPLIED ON THE MEGALITHIC HERITAGE: INTRODUCTION TO THE A-BIM AND THE ASSETS OF THE MODEL FOR THE DIAGNOSTIC AND THE DEFINITION OF CONSERVATION MEASURES

D. Groux[1], G. Quéré[1], P. Scaramuzza[1]

[1] A-BIME, France, didier.groux@a-bime.com

Commission II

KEY WORDS: H-BIM, A-BIM, Megaliths, 3D reconstruction, 3D mapping, Archives, Conservation, Restauration

ABSTRACT:

The diversity and the number of factors impacting the conservation of buildings heritage require to compare and confront a wide range of data to understand better the causes of the potential disorders. The HBIM technology and processes have already shown their ability to enhance the diagnostic of historical monuments throughout the past years and is now mature enough to be applied on megalithic heritage.
Focused on the case of the cairn of Gavrinis, this survey deals with the creation of the BIM model of the monument and its assets for the diagnostic. The 3D mapping of the disorders within the BIM model is highlighted. The pros of this workflow are also described before a short introduction to the following steps in progress.

1. INTRODUCTION

The conservation of cultural heritage is impacted by many kinds of issues and the diagnostic of the monument state of conservation must take them all into account. To be able to define efficiently the conservative measures for such buildings, the subject has to be treated holistically, including every factor at stake and confronting them.
The complexity of the diagnostic can be increased on some monuments when the former interventions are not properly known, if it is located in hostile environment and when the factors interact. In that case it can be hard to have a precise overview of the situation.
Nowadays new tools can be used for this purpose and various projects have been led in that field to adapt or to create solutions. One of them is the BIM (Building Information Modelling) which can be adapted to the cultural heritage: H-BIM (Heritage – BIM). Indeed, it enables to store a lot of data from diverse sources and to confront data easily in 3D.
However, its adaptation to the archaeological heritage was hampered by the differences between such monuments and the traditional buildings treated in BIM. But thanks to the latest developments it is now possible to manage such heritage with the BIM technology, becoming an A-BIM (Archaeological – BIM).
This article proposes to present and assess the methodology implemented for this project. The construction of the model will be detailed to emphasize all the different kind of data included in this work and different use cases will be presented to depict the assets of such model regarding conservation and restauration issues. This work being in progress, some future steps will be also described

2. PRESENTATION OF THE CASE STUDY

The cairn of Gavrinis is a masterpiece of the Carnacean area and is one of the most famous passage graves from the Neolithic. Located on the island of Gavrinis in the Morbihan gulf (Brittany, France), this monument consists of a circular stone construction covering a megalithic passage tomb. The internal structure is 16 meters long and is composed of a passage leading to a square chamber. The specificity of Gavrinis is the outstanding quality and quantity of the engravings on the surface of the megalithic structure's monoliths. This megalithic passage is ornamented with abstract and figurative motifs on the walls, floors and ceiling surfaces which represents a unique creation (Figure 1).

The monument was rediscovered during the 19th century and was excavated during the following decades. The initial access of the searchers was created at the summit of the construction: an important crater has been created by the successive generations of archaeologists at the top of the cairn. Since then, the monument has been visited by a growing number of tourists which harmed its conservation.

From 1979 to 1985, a major restoration program has been led to restore the supposed initial shape of the monument and to stop the ongoing degradations. Carried out by the preservation architects in chief, the intervention targeted mainly the summit and the south façade: restauration of the facade cladding and the filling of the crater above the chamber. The recreation of the initial volume involved to load the stones of the chamber. Due to the risk of break of the inner structural balance of the monument, it was decided to build a modern structure protecting the monoliths. This structure is partly visible nowadays thanks to the accessible space created by the construction of a vault above the covering stone of the chamber. Because of the ogival shape of the vault, this space is commonly called "the chapel". This masonry has been built with endogenous stones linked with cement-based mortar.

After this restauration program, some forms of degradation have been triggered. A general monitoring has been implemented under the responsibility of the LRMH (Research Laboratory for the Historical Monuments). Lately the cairn has been the subject of numerous surveys and research works led by Cassen. Aiming for a better understanding and documentation of the engravings (Cassen, Lescop, Grimaud and Robin, 2014), their attentive observations led to the awareness of the hazards threatening the monument. The last restauration campaign seemed to impact dangerously the conservation of the cairn. The active deterioration of the conservation conditions motivated the LRMH to carry out 4 surveys between 2013 and 2019 dealing with microbiologic analysis, the mapping of the visible alterations or the climate monitoring of the interior.

Willing to improve the conservation state, the department of Morbihan, owner of the site, has mandated the company A-BIME to lead a complete diagnostic of this monument and to propose a project of restauration.
The large number of issues at stake (former interventions, evolution of the interior climate, water penetration, microbiological infestation, development of salts…) makes traditional methods complicated. Every issue is interconnected to the others which requires a holistic approach. Aware of this difficulty, A-BIME has been developing for the past years the BIM technology for cultural heritage to deal with the issues of analysis, understanding and transmission of data regarding a monument. The methodology is now developed enough to be applied on cultural heritage as diverse as a megalithic monument.

3. RELATED WORKS

The possibility to have a model gathering all the data coming from a wide range of sources is very appealing but can be unreachable because of the lack of adapted tools. The strength of the BIM process is to be able to create a 3D model including the database of the building: the model stores as much data as desired.
Nevertheless, very rare case of BIM model has been done on megalithic monuments as shows the very few articles found in the open documentation. The complexity and the nature of this kind of heritage can led to consider the BIM technology as inappropriate.
The importance to merge as much data as possible in a single model has been highlighted for the past decade and the BIM was not always a chosen alternative. The complexity, the cost or the inaccuracy hampered the use of this technology. Other requirements such as the 3D mapping of data on the model was either inefficient or non-existent.
Other approaches were chosen because more suitable. Most of the time it has led to the use of GIS solution or to the development of dedicated tools, specialized for culture heritage such as the the Aïoli platform (Roussel, Bagnéris, De Luca and Bomblet, 2019). The main problems of these solutions are the lack of interoperability and the impossibility to integrate all the different kinds of data (temporal information, stratigraphic layers…).

Lately some projects have been undertaken in BIM for archaeological monuments. (Moyano, Odriozola, Nieto-Julián, Vargas, Barrera, and León, 2020; Bosco, D'Andrea, Nuzzolo, and Zanfagna, 2019). Although the BIM technology has been thought initially for modern construction, parallels can be drawn between a monument, such as the cairn of Gavrinis, and generic buildings and some workflows exist to create such complex shapes (Ewart and Zuecco, 2019; Pepe, Costantino, Saverio Alfio, Garofalo Restuccia and Papalino, 2021).
As the location and the quantities of alterations were a key aspect for the understanding of the conservation state of the cairn, a focus has been put on the 3D mapping of disorders and data in general within this monument. This enables to get areas and length with a high accuracy and to spatialize the data collected during this survey. Once again, the BIM technology hasn't been done to deal with 3D mapping, but recent works have shown that some ways are possible (Barba, Barbato, Di Filippo, Napoletano and Ribera, 2020; Di Paola, 2020).

This work is also inspired by former projects led by A-BIME where the same issues were encountered such as the structural diagnostic of the church of Gommecourt, or the diagnostic of the palais Carnolès in Menton. Depending on the the requirements of the surveys led by the company, different kinds of data are included in the BIM model created. The data included in every model depend on the needs and the requirements of the projects. The company has a strong experience in the field of the BIM dedicated to the cultural heritage thanks to its past projects and has already shared its developments to the research community (Bruez, Gandini and Groux, 2019).

4. APPLIED METHODOLOGY

The cairn of Gavrinis, is currently under a critical deterioration mainly due to former works of restoration led in the 80s. The important number of factors impacting the monument motivated the creation of a BIM model to gather as much data as possible within a unique document.

4.1 Model sources

The model has been created from diverse sources. The first of them are the archives stored by public institutions (national and regional archives, archives from the archeologic department). It brought key information about the past interventions which could have been forgotten through the time. This massive amount of data includes very diverse documents which turned out to be precious for the project and where then integrated to the model: archaeological surveys of the main façade, sketches of the foundations of the vault of the chapel, volume calculation of the masonry to be erected, administrative papers summarising the realized works…
The second source is the open-source data available online. Documents published by public institutions (ground survey, land register…) are a reliable base to build a BIM model. The

scientific publications from the archaeologists or from laboratories (specifically the LRMH) are also key documents to understand the previous works and analysis of the monument.
At last, a point cloud survey has been done with a high resolution to be able to capture even the thin engravings typical from this monument (Figure 2). The entire site has been surveyed: outside, inside and the space of the chapel above the chamber.

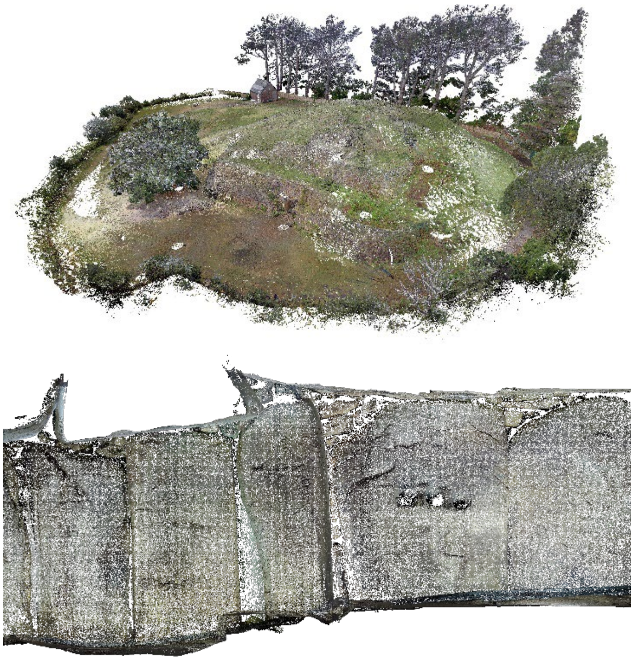

Figure 2. Overview of the point cloud and details of the interior passage tomb

4.2 Model construction

After this data collection, it has been merged into the BIM model. The documents can be integrated directly or indirectly depending on their kind and their use.
Pictures of PDF can be imported directly in the model. Their integration in it enables to recreate precisely some elements described on them and represents a layer of information. For instance, documents from the archives have been used to reconstruct the superstructure surrounding and covering the chamber built during the 80s to protect the dolmen (Figure 3).

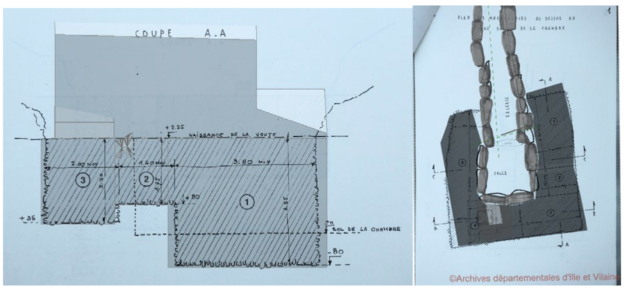

Figure 3. Section and plan view of the foundation masonry of the vault above the chamber: the sketch has been imported in the BIM model and was used to create the corresponding BIM elements.

The latest scientific works were incorporated directly in the model to understand better the stratigraphic units of the monument (Grimaud, 2015). Thanks to the 2D documents found, it was then possible to model in 3D the different layers of the tumulus (Figure 4).

To better understand the volumes of the monument, the monoliths composing the megalithic structure have been reconstructed in 3D. The high resolution point cloud made on site has been segmented per stone, meshed and cleaned. For most of the stones, only half of the monolith is visible. In that case the scanned surface was duplicated, mirrored and sewn together to create a closed shell. For the volume reconstruction, the iconography of the monoliths (drawings and plans realized during the late 19th and the beginning of the 20th). has been used to minimize the randomness factor. This element, a volumic element, was then imported in Revit, the BIM design software chosen.
In order to stress the difference between the scanned surfaces and the reconstructed ones, a systematic decimation has been carried out on the invisible surfaces. The resolution of the mesh of the hidden faces of the stones has been significantly deprecated so it is possible to distinguish the scanned face from the virtually reconstructed one.

Figure 5. Reconstructed monolith: the high resolution scanned face (left) and the decimated reconstructed face (right)

Other documents are integrated indirectly. The data they contain are stored in the BIM elements through parameters, but the documents are not imported in the BIM model. The parameters used are built-in or created especially for the need of the project. This possibility enables to include a wide range of documents in the model.
In any case, the link between the BIM elements and the documents are preserved. All the elements composing the model are linked to the documents which have been used for their creation. Indeed, each element stores a list of document IDs referring to the linked reference documents. The link between the BIM elements and the documents are included in the model allowing the query of the data source.

4.3 Data stored in the model

As the model is seen as the database of the monument, each element has been associated to numerous properties. The values for each property come either from documents found during the collect of data, or from onsite observation or survey led by A-BIME.

The model enables also to store temporal data. The evolution through the ages of the monument can be displayed: every element referred to a temporal phase of creation, and demolition if needed. The stratigraphic units and the BIM elements in general are dated. This enables to be accurate on the authenticity: whether an element have been reconstructed during the restauration program of the 80s or not; and date systematically every data integrated in the model.
The engraved stones for instance are characterized by a date, a material, a conservation state, whether they have been displaced or not (Figure 6) … The data can be easily displayed either visually through filters applied on the desired properties or through tables. Indeed, data contained in the elements can be plotted in tables and exported in CSV format.

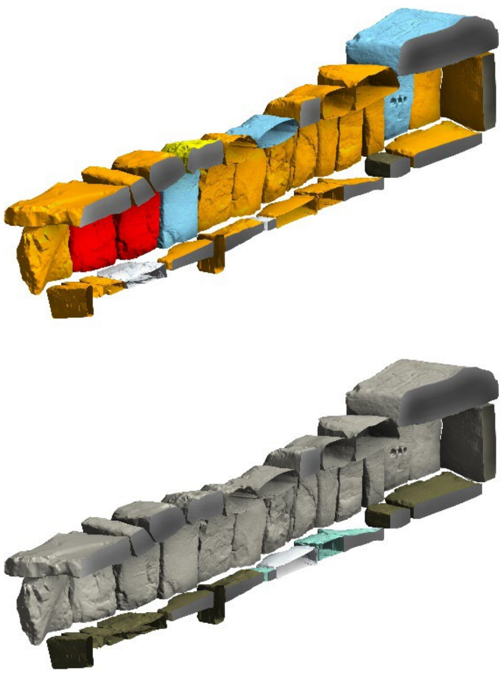

Figure 6. Colorization of the stones based on their material (top) and whether they have been moved or not (bottom)

Figure 7. Display of the points of interest: microbiological samples in green, sensors in purple and the remaining of former interventions in orange

This 3D reconstruction of the monument enables also to localise a wide range of interest points. Generic elements can be placed in the model and describe any kind of information. The classification of these elements in different types enables to query efficiently the information (Figure 7). For this project the hygrometric sensors, the mineralogic and microbiological samples, and the remaining of the former interventions which represents a danger for regarding the conservation have been integrated to the model.
These elements which doesn't correspond always to physical elements are not included in the BIM standards. Nevertheless, the important added value was a motivation to find a way to create them. These elements are stored in generic classes (IfcBuildingElementProxy class for the IFC interoperable file format) but they can be easily requested through the unique family name, or by their different type names.

As the observation and the mapping of the deterioration phenomena are a key aspect of this survey, the existing mapping documents (Vergès-Belmin, Touron, Bousta and François, 2014) have been included in the BIM model. The mappings carried out by the LRMH during the past years in 2D have been computerized, converted in 3D, and added to the BIM model. The original 2D areas and lines depicted in the documents were imported in Rhino software. They were then projected on the 3D surface of the stone elements and characterized by properties before being exported to Revit in the BIM model. This workflow was possible thanks to Grasshopper and the Rhino Inside Revit add-in which makes easier the interoperability between these two software (Figure 8).
The accuracy of the final mapping depends on the resolution of the 2D documents supporting the initial mapping.

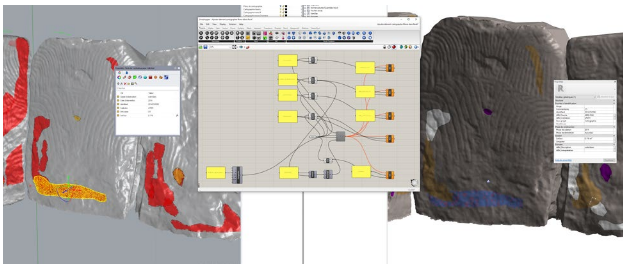

Figure 8. Element transfer from Rhino (left) to Revit (right) through Grasshopper (centre)

Once the mappings have been moved to the BIM model in 3D it was then possible to have precise quantities about the polluted areas and the lengths of cracks. As every element contains properties about the institution of the observer, the date of observation and a description, the BIM model enables to monitor accurately the evolution of these damages (Figure 9).

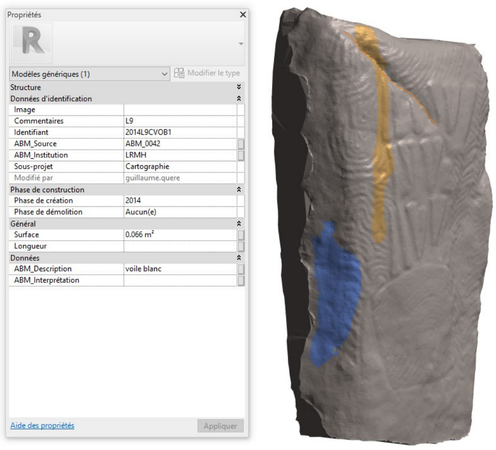

Figure 9. Example of a mapping zone and its properties

5. USE CASES OF THE BIM MODEL

Once the model contains this amount of data, it can be a powerful tool to support the diagnostic and can help the decision-making regarding conservation / restauration programs.

5.1 Data confrontation

The first asset of this model is to be able to directly confront data from different sources. The archives documents can be seen from a different point of view when they are placed at the proper location and confront to other recent data. It is also possible to read in parallel between different former analysis: for instance, laboratories analysis can be understood differently when they are crossed with hydrometric data.
A concrete example of this added value created from the cross-analysis is the comparison between the scaling zones and the location of the plastic film and the masonry structure built in the 80s (Figure 10). Indeed, the placement of these elements based on archival documents indicates that the plastic film could orientate the water penetrations to the inside of the monument, because of its deterioration or its misplacement, which would generate a scaling phenomenon on the stones touched by the trickle of water. In the chamber, this phenomenon would be caused by the trickle of water too from the vault above, till the stones bellow.

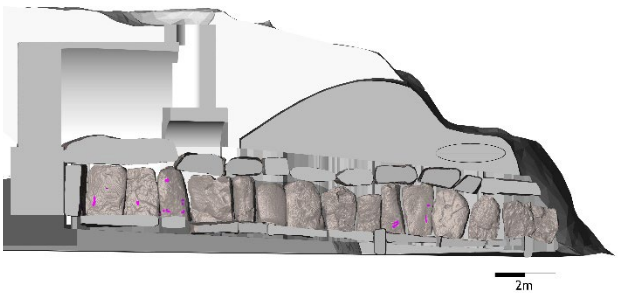

Figure 10. Longitudinal section view of the passage tomb: location of the plastic film (black ellipse) and the scaling zones (purple)

5.2 Data query

As seen previously, the BIM model is the database of the monument and can be queried easily and be exported. All the properties described before can be extracted as tables or filtered to enable to clearly visualize the data.
But it is also possible to sum and to count quantities or elements queries. As all elements have a volume, an area, or a length, it is easy to get detailed quantities per material, per deterioration phenomenon (Table 1), or to count the precise number of elements such as the microbiological samples.

Deterioration phenomena	Quantities	
	m^2	m
Scaling	0.22	-
Algae colonisation	0.95	-
White veil	3.43	-
Delamination	-	4.08
Cracks	-	44.65

Table 1. Table export from the BIM model: quantities (area and length) of some deterioration phenomena

Summarised in tables, these data are easily readable and transferable. This enables to synthetise efficiently the data.
The data query can also provide advanced visualization of data in the model. Graphical technical documents can be exported easily from this 3D reconstruction.

5.3 Interoperability and further uses

The BIM model can be also exported to other software to perform simulations for instance. The interoperable file format, the IFC standard, enables to exchange the model (geometric shapes, and data) between different software. The BIM model becomes the central model from which other models are created for different purposes. This possibility enlarges the uses of it and enables to create new information.
For this project, the importance of the structural issue has motivated the export to a structural software to perform a FEM (Finite Element Method) simulation. As no calculation notes have been found in the archives regarding the comportment of the ceiling stone of the chamber without the protection vault of the chapel, an estimation of its behaviour without this contemporary structure is in progress (Figure 11).
Exports could also be done to perform thermal simulations for instance. Every software able to read the IFC file format could communicate with this model.

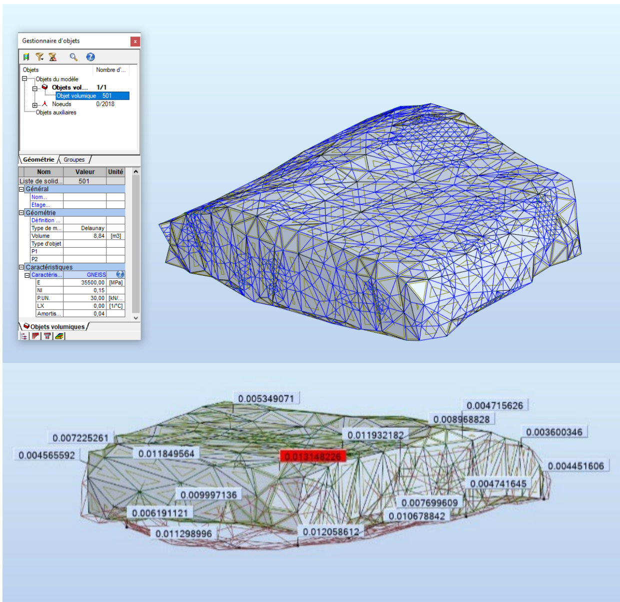

Figure 11. Ceiling stone of the chamber in the FEM software (top) and its deformation in mm after simulation (bottom)

6. CONTINUATION

This project is still in progress and new steps are about to come. Regarding this paper, a new mapping campaign of the deterioration phenomena will take place. It will provide more updated and precise data about the visible deteriorations in the dolmen. These observations will be integrated in the BIM model and dated. It will then be possible to describe the evolution of the different phenomena and to calculate the amount of area to be treated to prepare the future restauration.
The current way to transfer on site observations to the model can still be improved. The important number of steps to implement the mappings is still time consuming and could be easily reduced with a more digital way to take notes in the monument.

A-BIME must bring in fine precise conservation measures and restauration proposals to the contracting authorities. Different scenarios have to be presented. These one will be integrated in the BIM model too. The design of the potential installation can be modelled in the BIM software. This provides information about the volumes of material, the costs of the project and brings an overview of the impact of the future intervention on the site.
In general, this model can evolve with the monument. Once the project of A-BIME is over, the whole model will be given to the authorities which could keep it updated with the future works. The BIM model is flexible enough to follow the evolution of the cairn.

The reconstruction of the monoliths could also be improved. Indeed, if some faces have been scanned, others have been hypothetically reconstructed. These parts have to be considered differently by the users. Even if the resolution of the mesh has been changed to make visible the limit between scanned surfaces and hypothetically reconstructed surfaces, it should appear more clearly mostly for non-experienced users. This issue of scientific transparency is one of the eight principles of the Seville Charter (Lopez-Menchero and Grande, 2011) which provides a framework for the digital modelling of the cultural heritage. The implementation of a standard to differentiate surveyed and non-surveyed pieces (hypothetic), common to all the different modelling technologies, would be a milestone for the unification of the cultural heritage digital models.

7. CONCLUSIONS

From a technical point of view, it is now possible to model shapes with a high complexity and to integrate them in a BIM model. The data management enabled by this technology is very powerful and leads to a better management of the monument. This powerful tool has shown its usefulness on archaeological heritage.
This amount of data stored in the model enables to understand better the issues at stake and to confront the data from different sources. The wide range of data sources involved enlarges the scope of this survey. Once transmitted to the decision makers, all this data enables them to understand in detail their monument.
This tool is also an asset to share and transfer knowledge to the various actors who work on this project. The workflow is easier and faster, and the data is reliable. Thanks to this model, the archaeologists, the competent authorities, and the laboratories have a common relevant knowledge to take decisions.
But this model is not only a database of the monument, it generates also new information. The confrontation of data or the requests can create a significant added value. The power of this BIM model is to be interoperable with other BIM software but also with other technical software such as FEM software. This A-BIM model stores efficiently data and can evolve in a large digital environment.
The high resolution of the geometry of the model and the 3D mapping enables to have a very accurate quantities of decay and areas that must be treated. This model becomes a powerful tool for conservation planning and monitoring.
Nevertheless, the flexibility of the design has still to be improved. The numbers of steps to perform such model can be a break to its creation.
The data acquisition could also be improved specially regarding the observation and the mapping surveys. A digital way to map on site observations would significantly cut the modelling time and reduce the approximations.

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