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► **To cite this version:**

Sarah Janvier-Badosa, Chiara Stefani, Xavier Brunetaud, Kévin Beck, Livio De Luca, et al.. Documentation and analysis of 3D mappings for monument diagnosis. Built Heritage: Monitoring Conservation Management, 2015, 10.1007/978-3-319-08533-3 . hal-02090607

**HAL Id: hal-02090607**

**<https://hal.univ-lorraine.fr/hal-02090607>**

Submitted on 4 Apr 2019

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# Documentation and analysis of 3D mappings for monument diagnosis

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**Abstract** The restoration and preservation of built cultural heritage requires a good knowledge of its history and its current state of conservation. Heritage conservation professionals are used to perform mappings to record and disseminate data relative to the monument. Data to be collected are heterogeneous, starting from the oldest sources (such as archives or iconographic manuscript) up to field observations. This study is applied to the documentation and analysis of the state of conservation of the East tower in the castle of Chambord. The produced mappings concern the dating of stonework, the nature and origin of each stone, and the distribution of degradation patterns on the outer walls. To enable the graphical drawing and viewing of the different mappings, it is necessary to produce a suitable digital medium. In this study, the medium is a textured 3D model as a mean to characterize accurately and actually all surfaces, including those that cannot be viewed on a 2D projection. This 3D model is associated to the NUBES database to store and analyse all collected data. NUBES is a web-based open source platform for the representation, documentation and analysis of architectural elements. This information system has been specifically developed to include an interface dedicated to the drawing vector mappings and to their organization into hierarchical layers. Results of this study can be used to improve the monument diagnosis and our knowledge of weathering processes.

## 1. Introduction

As part of the SACRE project (Degradation monitoring, characterization and restoration of limestone monuments), the castle of Chambord has been studied using various approaches, whether historical or scientific. The aim of this project is to achieve a better understanding of the building and to be part of its preservation.

The East tower of the castle has been selected as the main subject of the study with the aim of creating a digital health record of this tower. Steps of this process, including the definition of dating, nature, origin as well as degradation of stones, have been identified in previous works [Janvier-Badosa *et al.*, 2013; Janvier-Badosa, 2012]. Today, digital archiving in databases can constitute an innovative solution in order to classify this heterogeneous corpus of data, to compare these data and extract useful information for professionals of heritage conservation. The existing NUBES system was used. Developed by the MAP-GAMSAU laboratory (Marseille, France), NUBES is a web-based open source platform for the representation, documentation and analysis of architectural features [De Luca *et al.*, 2011]. NUBES is based on a database in which are inserted architectural 3D representations. This interface allows the storage of heterogeneous data, the real time manipulation of three-dimensional geometric representations, as well as the online access and management of data. Originally, NUBES did not include the necessary features for the creation of a digital health record on the state of conservation of buildings, and therefore it has been adapted to match the needs of the SACRE project [Stefani *et al.*, 2013].

This article is structured in the following way. The first part describes the different methodological steps of a digital health record creation using NUBES system. The second part of this paper describes a practical application of this methodology on a span of the East tower, in order to illustrate the adopted method and demonstrate the possibilities to improve decisions by cross-referencing data. Finally, limitations and future prospects of this approach will be discussed.

## 2. Methodology and features of NUBES

### 2.1. The 3D model

The first step to create the health record of a building is its graphical representation. In the field of conservation and valorisation of cultural heritage, many techniques for acquiring three-dimensional digital models have been developed.

In this study, the graphical representation should satisfy various requirements: it should be convenient to achieve, scientifically accurate and precise, and of acceptable image quality to ensure a correct visualization of the smallest required component: a stone. So, photomodeling technique has been adopted [Brunetaud *et al.*, 2012a]. After the acquisition of geo-referenced points using a tachometer, we took pictures on a regular basis all around the tower. The ImageModeler software has been used to calibrate and orient photographs to each other. The building volumes were then defined as precisely as possible by the juxtaposition of geometric shapes. Textures, extracted from oriented photographs, have been applied to the faces of the 3D model. Finally, the building was divided into coherent architectural entities (windows, spans pilasters, capitals...). This division is necessary for the 3D model of the tower in order to insert it into the NUBES Information System. This step consists in manually upload 3D elements on a server by means of the user interface, and includes the storage of the x, y and z coordinates of the barycentre of each 3D entity, as well as the upload of each texture in the database. Once all entities are registered, it is possible to navigate through the 3D model, and to select an entity whose unfolded texture can be displayed in a 2D interface for semantic annotation purposes (figure 1). Photomodeling allowed to obtain unfolded 2D textures: even if textures are distorted, readability of textures is optimised and this techniques permits to display all faces of architectural elements, including the hidden parts. The size of the drawing interface is flexible and can be increased or reduced in height as needed, resulting in the reduction or expansion of the 3D interface.



Fig. 1. Graphical user interface of NUBES

## 2.2. Graphical representation of data

### 2.2.1. Conventions of representations

The basis of an architectural study is the representation of data for critical and analytical thinking [Núñez Andrés and Buill Pozuelo, 2009]. The realization of mapping, from drawings or photographs, is a common approach for many professionals in heritage conservation but the type of mappings varies according to the field and the purpose of the work: archaeologists or architects in charge of the heritage with historical data [Reveyron, 2002; Bryant *et al.*, 2007], especially different phases of construction or restoration, at different scales and with several levels of accuracy. As matter of example, these representations can be applied to a complex of buildings [Stefani *et al.*, 2009] or to a neighbourhood, where the smallest unit is the scale of the building [Saygi and Hamamcioglu-

Turan, 2009], or simply to a facade where the smallest unit is the scale of the stone [Akbaylar and Hamamcioğlu-Turan, 2007], as in our case.

Geologists working in conservation of historical monuments most often practice stone by stone mapping indicating the nature and origins of each stone [Montel, 2007; Rautureau, 2001], and conservation scientists generally produce graphical representations of the different kinds of degradation, in the context of degradation monument diagnosis [Janvier-Badosaet *al.*, 2013; Akbaylar and Hamamcioğlu-Turan, 2007; Fitzneret *al.*, 2002].

### 2.2.2. Mappings in NUBES

The realization of mappings was not originally an existing tool in NUBES. The platform has been adapted to match the needs of the SACRE project [Stefani et al., 2013]. Now, it is possible to select an entity of the 3D model, to display its unfolded texture in 2D, and to produce the mappings on this 2D image. In order to accomplish this task, a vector graphics editor was adapted and integrated into the NUBES platform to draw/edit mappings using hierarchical layers.

A colour corresponds to each layer: colours enable to identify easily annotations that are drawn and projected onto the 3D model. Before drawing the shape, the user selects the layer corresponding to the item he wishes to map. Mappings are made on each 3D entity, one after the other, when they are developed in the 2D drawing interface. The result of the drawing of mapping is a complex juxtaposition of polygons that can be of two types (Figure 2):

- Free shapes, for example following the contours of the damage. Depending on the case, the degradation can cover several stones and mortar joints, or a stone - or part of a stone -, with the exception of mortar joints.
- Shapes which strictly follow the contour of stones without mortar, called "stone by stone" contour. These contours are drawn on a layer called "matrix". They are duplicated in other layers to keep geometric coherence. These layers correspond to the known information for each stone (dating and origin of stones).

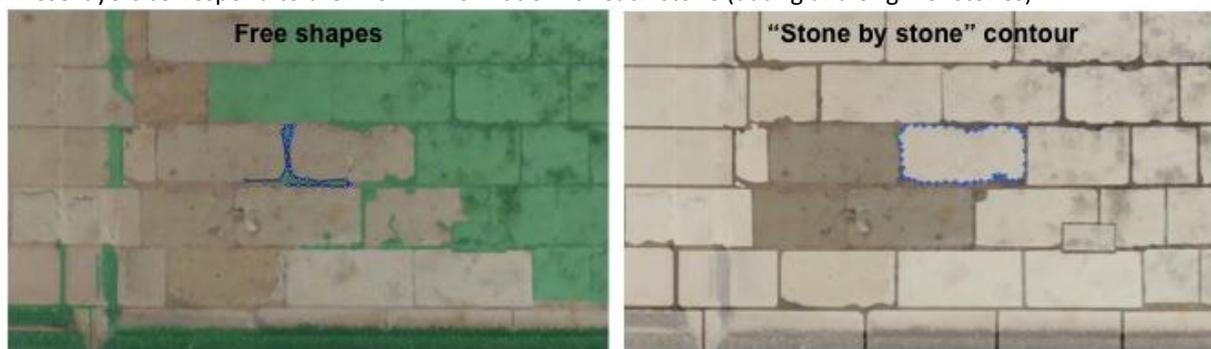


Fig. 2. Drawing method of the two types of mappings

### 2.3. Display and data processing

Mappings are then stored in the database and shown on the 3D model (figure 3). NUBES allows the cross-referencing of mappings in real time in the 3D scene. In the 3D interface, the user consults mappings by selecting the layers to be simultaneously displayed. Among mapping features, a statistical analysis tool allows the automatic calculation of areas concerning drawn surfaces. Percentage is computed as the ratio between the areas obtained for each class of analysis and the total area of the unfolded entity.

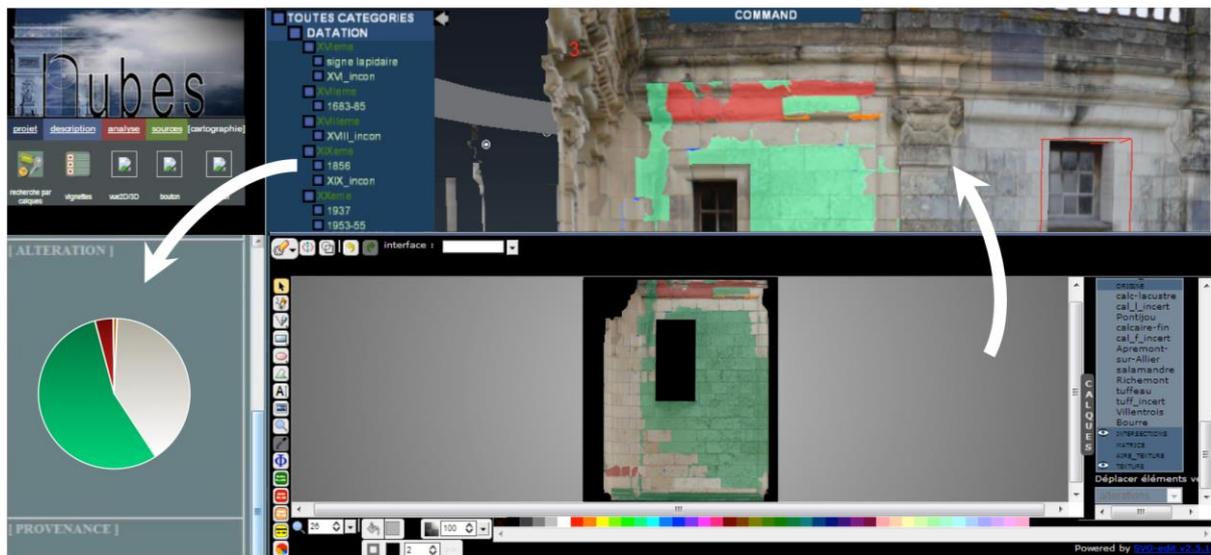


Fig. 3. Display of mappings of damage on the 3D model and statistical analysis of weathered surfaces

## 2.4. Archiving of associated data

NUBES allows data storage, including written and iconographic historical archives that constituted the basis for the creation of mappings. The 3D model can display specific points (reference marks), which correspond to files stored in the database. Formats and types can be various and include details of photographs, reports of restoration, ancient texts, plans, point clouds of specific areas, as well as to descriptions, reports or analysis of samples. These documents can refer to the entire building as well as to a specific component. The main advantages are their free on-line consultation and the easy visualisation of their position in the 3D scene. Moreover, they are consulted online.

## 3. Practical application

### 3.1. Implementation of mapping and statistical analysis

By means of *in situ* observations and the study of historical archives, we defined the semantic structure of mapping data. The semantic structure is based on hierarchical layers of terms related to the domain of conservation. These layers are created in a dynamic way, according to the list of terms stored in the database. In this study, various mappings were made (Figure 4): the mapping of date of the stones, the mapping of origin and nature of the stones, and the mapping of the distribution of damages [Janvier-Badosa *et al.*, 2013].

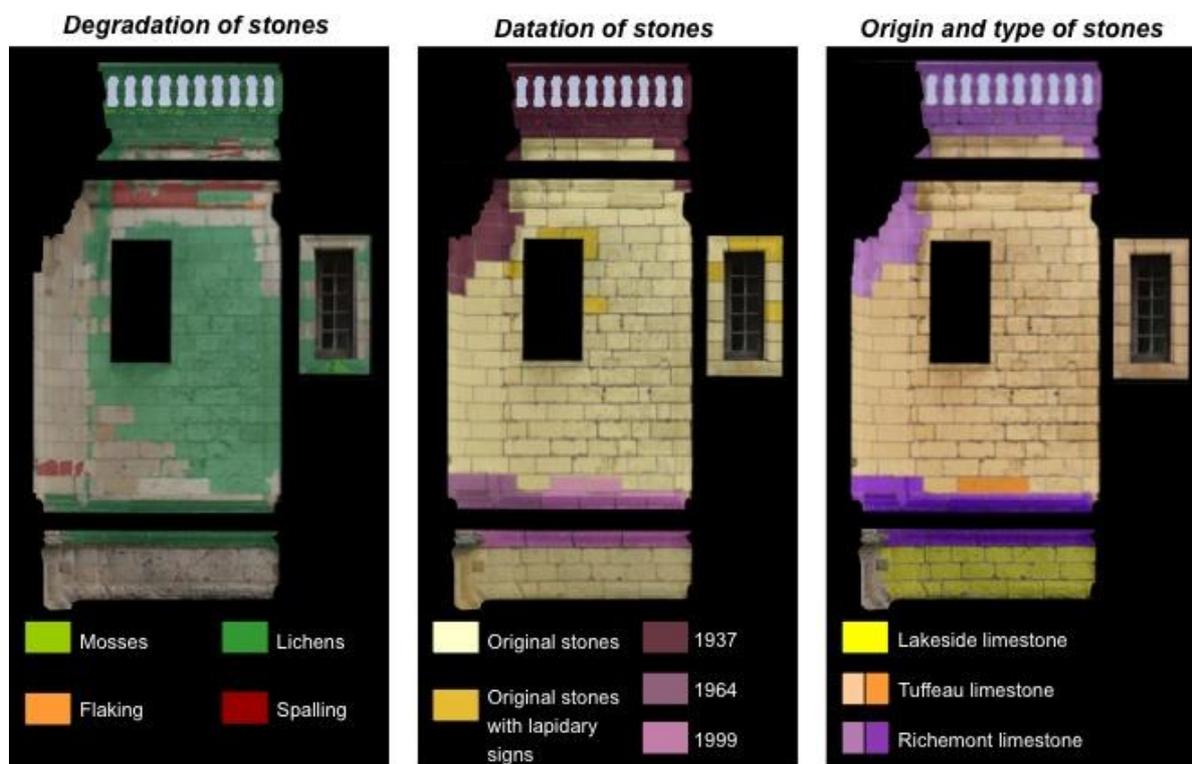


Fig. 4. The three types of mapping applied to the first span of the tower

### 3.1.1. Mapping of degradations

The deterioration measured in the castle of Chambord belongs to three categories. Material losses under the form of breaks have been found on relieves. These are limited and irregular alterations, whose origin is often anthropogenic. Biological colonizations have also been studied, mainly mosses and lichens from different species. Finally, detachments were identified: scaling of stones. These last ones have two forms: spalling and flaking. Each of these aspects is structured in layers and sub-layers recorded in NUBES. To draw a particular degradation, it is necessary to be positioned on the corresponding layer, and to draw its contour on the 2D unfolded texture. The mappings produced in the first span of the East tower are representative of the rest of the tower (Figure 3). Biological colonizations are the most extensive change since they affect 55% of the wall surface of the span. However, they constitute the least damaging degradation, since they are relatively superficial and reversible. On the contrary, spalling (3.8%) and flaking (0.2%), although not extensive, are extremely destructive because they lead to an irreversible loss of material.

### 3.1.2. Mappings of dating and origin of stones

Dating of stones identified on the castle of Chambord varies from the 16th to 21st century. Dates correspond to the ones of construction of the castle, as well as to the various stages of restoration. Some stones are easy to date because they present lapidary signs, traced by stonecutters only during the 16th century. For other stones, information is provided by *in situ* observations coupled with the study of historical archives, and dates are suggested with different degrees of certainty. For this reason, in the mapping of dating, there are specific dates (concerning specific years) as well as great ranges (concerning centuries). For the first span of the tower, the replacement stones (18%) correspond to three dates: 1937 for the upper parts, and 1964 and 1999 for the lower

parts. The remaining stones of the span are supposed to be original (16th century), except for four stones on the window frame, with lapidary signs, therefore being without a doubt from the 16th century.

These same sources (observations and archives) provide indications on the types of stones. They point out that the castle was built with tuffeau, a porous and soft limestone extracted locally. The basements are lakeside limestone, whose properties allow the preservation of tuffeau, limiting capillary rise from the ground. Documents also show that most of the 20th century restorations were made with Richemont limestone, less porous and more resistant than tuffeau. In some cases, quarries from these stones can be identified.

The stones are drawn one by one, on the layer called matrix described above (figure 2). The contours of these stones are then copied and pasted into different layers of dating and nature of the stone, according to their characteristics. In addition, stone by stone drawing allows to visualize accurately the morphology of mortar joints, the production technique (large and irregular, or fine and straight), providing information also on its date of installation, and by extension, the date of installation of adjacent stones.

## **3.2. Contribution of this methodology**

### **3.2.1. Application to various disciplines**

Considered individually, these recorded and mapped data can help in understanding the building's history and its present state. In addition to the purely statistical aspect, these maps provide also other information.

For example, the mapping of degradation on a three-dimensional model allows to visualize the distribution of damage, depending on the location or orientation (near reliefs or not, upper or lower part, preferentially at the north, south...) and thus to deduce recurring factors that could cause degradation. In figure 3, the mapping of degradation of the first span shows a preferential localization of spalling in the upper and lower parts of the building, near the reliefs (mouldings). In addition, we know that the forms of degradation observed in the castle of Chambord gradually spread over time. The ability to draw at regular time intervals new contours of degradation allows to identify its evolution and to evaluate the kinetics of its development.

The mapping of dates and origin of the stones can provide new information of interest to historians and archaeologists. The "economy of construction" is an emerging discipline of history, still waiting for quantitative accurate numerical data. The count of stones, the position of the lapidary signs or putlog holes, can give indications about construction techniques, the progress of work in the 16th century, or later reworking. The use of different types of stones depending on the period, or the location of different types of stones on the building (structural role, technical, aesthetic...) are clues of interest for archaeologists and historians, especially if they are related with a 3D representation of the building.

### **3.2.2. Crossing data and application to the Heritage Conservation**

The NUBES database enables to save a huge amount of data in the fields of archaeology, history, scientific preservation, etc. But its main contribution is the capability of cross-referencing these data, usually treated separately, in each discipline.

For example, by cross-referencing the mapping of damage with the layer of matrix stone by stone, it is possible to know if a specific degradation concerns only stones, or both stones and mortar joints. By combining mappings of degradation with mappings of nature of stones, it is also possible to observe the relation of degradation, with one or more types of stones. Finally, crossing mappings of degradation with mappings of stone dating allows to know if the damage preferentially affects old or recent stones. Data cross-referencing can then be quantified through statistical analysis tools. In the first span of the tower, as well as in the entire castle, biological colonization affects all kinds of stones and are independent from the date of stones. Flaking is not based on the stone dating, but affects only the fine-grained limestone (tuffeau limestone and Richemont limestone). Finally, spallings only affect original tuffeau limestone.

After the recording and processing of cartographic aspects, the future step would be the simulation of the evolution of damages. Indeed, in the mappings, contour degradation is reproduced in vector drawing. As geometric features can be extracted from its shape, a possibility is to apply to this form, automatic transformations, that would follow several criteria defined by the observation of physical aspects. As matter of example, it would be possible to increase the weathered surface, while limiting or slowing down the expansion when the degradation

lies near a mortar joint or a stone of another nature. By defining the position of the mortars, the stone by stone drawing is a key element to illustrate this evolution. It is necessary to integrate a temporal concept to these evolutionary patterns, however, for now it is still difficult to define, without (the contribution of the) experimental and numerical simulations.

Finally, the system of data storage in NUBES allows to associate items to mappings and to locate them precisely: this is the case for sampling and analysis results of degraded stones, or restoration reports showing the date of replacement of stone and the quarry exploited for restoration.

Once adapted to the needs, the NUBES platform represents an entirely digital health record of the state of conservation of buildings. NUBES is primarily a system associated with a dynamic and therefore progressive database: unlike written reports or database on CD-Rom, data can be upgraded, extended, and shared via online interface. In this way, results are available to all professionals of heritage preservation concerned with the history and the conservation of the castle of Chambord.

#### 4. Conclusion

A better comprehension of the past of a monument is possible through the study of historical archives and in situ observation. In this specific case, several years of research contributed to bring to light the history of stones of the castle of Chambord, by knowing their dating, type, origin, and state of degradation. All these elements contribute to the establishment of the health record of the monument.

The 3D model of the tower provides support to the collected data. It was necessary to combine the 3D model with a database to store the collected data, to cross them for analyse them. NUBES system was used. In addition to the navigation in the 3D scene, an interface allows the vector drawing on the elements of the facade. Drawn information is structured in layers of hierarchical levels. Each layer corresponds to a colour code to locate on the facade, the areas covered by a layer. The mapped information can then be projected onto the 3D model to visualize its spatial distribution. Statistical analyses can be performed to precisely quantify the area proportion for each layer. Moreover, the most interesting application is to cross the different layers to statistically test spatial correlations. This latest application can be usefull to produce quantification of hypothesis, like the particular sensivity of a stone to a specific degradation, or the typical age of stones subjected to a type of degradation. This digital health record allows to combine all these accumulated data, to confront them and extract useful information to different professional people of heritage preservation.

Future researches related to the use of a multi-dimensional database for the preservation of cultural heritage are various. Infrared thermography for example is a method of non-destructive diagnosis widely used in the study of monuments, and the intersection of these data with visible data already mapped is a prospect of work. Similarly, for the moment, this system allows the recording of data related to the past and the present state of a monument. The prospect of include temporal data in connection with the future evolution of damage over time, for example, constitutes a major interest for curators to predict risk areas and organize restoration operations of the monument.

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