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The VALMOD project: historical and realistic 3D models for the touristic development of the Château de Chambord

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Abstract. The VALMOD project is a French regional scientific program whose objective is to propose innovative scenarios for the tourist development of built heritage from the combined contribution of *in situ* 3D acquisitions, informatics, and history. This interdisciplinary approach aims to stage original historical content thanks to appropriate 3D models and the use of adequate media for the targeted public. This communication presents several examples selected among the applications developed during this program: the creation of a global model able to precisely describe the whole architecture of the Château de Chambord; a 3D print of the double staircase that can be unscrewed to separate the two stairways; replicas of pieces of the lapidary deposit to make them virtually easy to handle. The challenges concern both technical aspects such as the precise registration of thousands of multi-scale scans or the creation of manifold meshes from point clouds, and project management aspects such as making the interdisciplinary approach effective.

Keywords. 3D acquisition; tourist development; built heritage; interdisciplinary approach

1 Introduction and scientific context

The VALMOD project is a scientific program founded by the region "Centre Val de Loire" of France for the period 2014-2017. It is led by the Civil Engineering research team of the PRISME laboratory at the University of Orléans. The partners are the CESR laboratory (history of the Renaissance), the LI laboratory (informatics), and the "Domaine national de Chambord". VALMOD is part of a group of 7 programs concerning the Château de Chambord, named "Chantier Chambord Château", which is itself part of a larger group of about 100 programs concerning regional heritage named "Intelligence des Patrimoines". Several completed or still ongoing programs constitute the scientific and collaborative basis of VALMOD: SACRE (PRISME 2008-2012); REPTURE (PRISME 2010-2013); MONUMENTUM (MAP/GAMSAU 2013-2017); RIHVAGE (CESR 2013-2014). The SACRE program (Degradation monitoring and restoration of limestone monuments) laid the methodological groundwork for the study of the origin of degradations, thanks to the creation of a digital health record of the monument [1, 2, 3, 4, 5, 6, 7, 8, 9]. During this first program, laboratory and in-situ experiments, analysis of archives, and 3D acquisitions for the conservation of the Château of Chambord started. The REPTURE program (Restoration of damaged statues: transversal methodology of structural analysis) was devoted to developing a method to assess restoration options for broken statues, thanks to its mechanical simulation based on the 3D model resulting from laser scanning. The MONUMENTUM program (Numerical modeling and database management for the conservation of masonry structures) stems from the SACRE program, and focuses on breaking scientific barriers concerning the 3D acquisition pipeline and database management, to enable all actors in the conservation field to query the digital health record. Finally, the RIHVAGE program (Interdisciplinary research on the history of castles and courts in the Val de Loire during the medieval and renaissance period) established a database to organize and disseminate digital archives concerning Chambord.

A high potential for tourist development could be expected from all these research programs. However, this potential was underexploited due the disciplinary segmentation of the related scientific fields, each one generating hard to find, complex, and fragmented results. The VALMOD program is an attempt to promote the tourist development of scientific results based on the hypothesis that such a development can only be the result of a multidisciplinary approach, encompassing actors working in different media. More practically, the objective of the VALMOD program is to contribute to the tourist development of the Château de Chambord, an icon of regional, national and global heritage, through the use of 3D models resulting from in situ acquisitions in order to stage historical content. From the scientific point of view, the collection or acquisition of architectural and historical data, already started in previous research programs, is pursued with a systematic emphasis on the potential for tourist applications. The challenge is to promote a "have fun and learn" approach to scientifically validated results

by using appropriate media to target different publics, while trying to minimize the usual weakening induced by outreach.

The VALMOD program can be divided into four main tasks:

The first task consists in completing the 3D acquisition campaigns of the Château de Chambord and other heritage constructions included in the Domaine national de Chambord, using photogrammetry based on multiple image correlation and laser scanning, added to a topographic survey. The processing of the resulting raw data involves the registration of multiple scale acquisitions and the fusion of data from laser scanning and photogrammetry. The results of this first task are the creation of different 3D models with varying resolution and spatial segmentation in order to optimize the viewing experience.

The second task consists in collecting historical and architectural archives, and creating a synthesis in order to highlight the most promising documents to be used for tourist applications. The main application concerns the construction and restoration steps. The definition of the chronological and spatial evolution of the monument based on archives such as iconographic documents and deeds is the main input for the creation of alternative chronological 3D restitutions.

The third task aims at proposing and testing different enhancement scenarios of the produced and collected data, taking into account both 3D acquisitions and historical inventories, and by cross-checking the opportunities for tourist applications with the other programs of the "Chantier Chambord Château". This task is mostly interdisciplinary; the challenge is to promote the involvement of all partners in the creation of innovative, coordinated and scientifically validated products.

During the last task, the most promising and fully developed enhancement scenarios will be tested at the Château de Chambord in the form of pilot actions. Here, the challenge will be to propose the suitable medium for a targeted public. The relevance of the resulting experiment will be assessed by analyzing the public's perception.

The objective of this communication is to present some examples selected among the applications developed, halfway through the VALMOD program. According to the structure of the program, these examples are candidates for task 3 (establishment of enhancement scenarios). Attention is paid to explaining the challenges and the lessons learned from this experience.

2 Protocol for 3D acquisition of architecture

Before presenting the examples of applications, and in order to clarify the scientific and technological issues, a preamble about the common feature of all scenarios is the requirement of resorting to 3D acquisition. Two different technologies are used in the VALMOD project: laser scanning and photogrammetry based on multiple image correlation.

For the laser scanning of architecture at the Domaine national de Chambord, we used exclusively a Faro Focus 3D (phase shift laser scanner), whose precision and acquisition speed are satisfactory when the working distance is between 1 and 30 meters. This scanner has an embedded coaxial digital camera for the acquisition of color, so as to provide colorimetric information on each point of the resulting scans. However, the color information is inhomogeneous and sometimes approximate. The main processing task consists in spatial registration, which can be automated thanks to the positioning of spherical references, or conducted manually by the localization of reference points directly in the scan [3].

For photogrammetry, we used a Canon 6D digital camera (21 MPixels; 24x36 mm sensor) with various lenses (24 mm; 105 mm; fish-eye), with a tripod. We applied this technique to several facades of the Château de Chambord and to some pieces of the lapidary deposit in order to obtain a better color restitution compared to laser scanning. To process the photographs in order to obtain 3D models, we used MicMac (open source and free software), which is based on multiple image correlation. This software is particularly efficient in creating accurate 3D models by taking into account control points from topography.

3 Examples of applications

3.1 Global model of the château

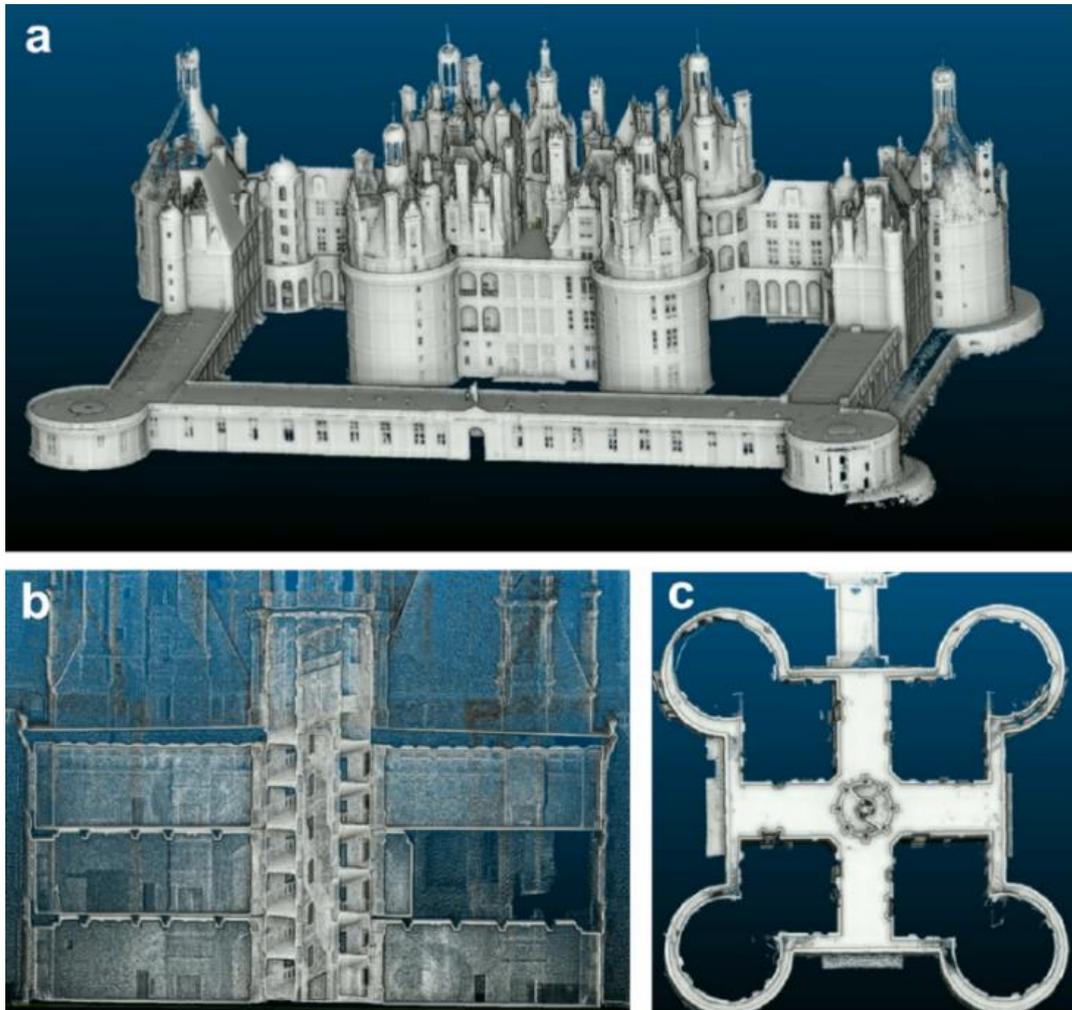


Fig. 1. (a) Rendering of the point clouds representing the Château de Chambord; (b) Vertical slide of the keep; (c) Horizontal slide of the keep.

The creation of a global 3D model of the Château de Chambord from laser scanning is the first application. This model can be used to present the results of 6 years of successive 3D acquisitions. Many students from the Civil Engineering department of Polytech Orléans (Engineering School at the University of Orléans, France) have contributed to this progressive acquisition. For outdoor laser scanning, we used spherical references to facilitate the registration process, whereas for indoor laser scanning we performed only manual registration so as to avoid impacting the scanning with unnecessary outliers. We acquired the geometry of the whole outside facades of the château, except for some parts of the roof because we performed terrestrial laser scanning only. Moreover, we acquired some indoor scenes such as the double staircase, several restored attics, and one modular housing of the keep. Our ground resolution ranged between 2 mm for the most proximal points and 5 cm for the most distal ones. The registration of all the scans (about 400, i.e. 10 billion points before fusion) taken at different scales into one 3D model represents a real challenge, and the refinement of registration at the millimeter scale for some parts is still in progress. After fusion and resolution limitation, point cloud models of no more than several hundred million points can be obtained. These models can now be quite easily handled by recent software and computers to create real-time rendering (**Fig. 1a**). Additionally, this kind of 3D model can be processed to extract original architectural information such as vertical (**Fig. 1b**) or horizontal slides (**Fig. 1c**), planar and cylindrical projections to create high-resolution metric elevation. This global model has been used to illustrate two national television documentaries concerning the Château de Chambord [10, 11].

3.2 3D print of the double staircase

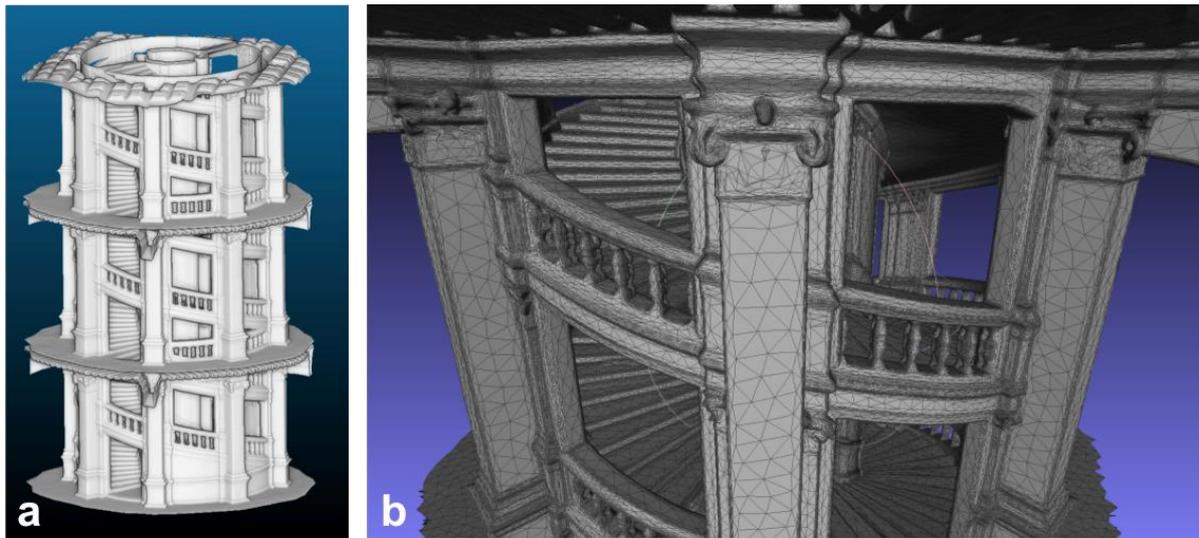


Fig. 2. (a) Dense point clouds of the double staircase; (b) Light and manifold solid model of the double staircase

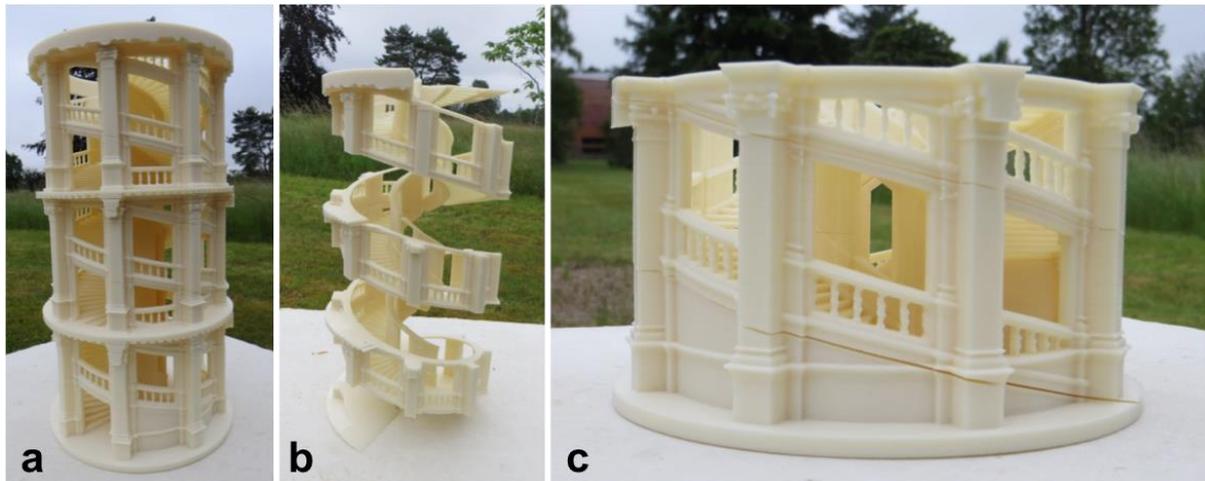


Fig. 3. (a) 3D print of the model; (b) Stairway unscrewed from double staircase; (c) One level composed of two stairways

From the global model of the Château, the double staircase was segmented. One of the challenges here was to define a processing pipeline to create bridges between the formats of data from in-situ acquisitions (dense point clouds, Fig 2.a) to ready-to-print 3D sketches (light and manifold solid model, Fig 2.b). From the educational point of view, the most important point was to segment this double staircase into two separate helicoidal stairways so that it could be unscrewed (Fig 3.b). Finally, the 3D print of the double staircase, which is about 41 cm high (Fig. 3.a), is composed of 3 levels, each one composed of 2 stairways (Fig. 3.c). Additional features were integrated such as pins to help centering and relative positioning. The print of each level took about 70 hours.

3.3 Pieces of the lapidary deposit

This third application deals with the photogrammetric acquisition of some selected pieces of the lapidary deposit of the Château de Chambord. The lapidary deposit is a place where stones removed during restoration are conserved due to their particular interest. These pieces are therefore precious, always damaged, and sometimes voluminous, which prevents their easy handling. In order to make it possible to handle them without touching them, we decided to create digital replicas using photogrammetric acquisition. Here, the challenge was to obtain comprehensive complementary orientations while having sufficient and constant illumination for each point of view. In this case, photogrammetry was used to create high resolution point clouds with high color fidelity (Fig. 4).



Fig. 4. : Rendering of 3D textured model of pieces of the lapidary deposit of Chambord, by photogrammetry.

4 Lessons learned

The main lessons learned concern the solving of technical challenges, and making the interdisciplinary approach effective.

The main technical challenge is due to the fact that we decided to rely exclusively on rigorous *in-situ* acquisitions. That makes the resulting raw data complex, inhomogeneous, dense, voluminous, and sometimes locally incomplete. Moreover, the combination of laser scanning and photogrammetry, including the accurate projection of pictures oriented using photogrammetry on meshes resulting from laser scanning involved developing a specific code, especially for the implementation of the Fish-eye lens. More globally, the processing and the viewing of our models required up-to-date technological surveillance due to recent evolutions of software such as MeshLab and CloudCompare.

To make the interdisciplinary approach effective, obviously, the key was to create bridges between disciplines. This means that at least some scientists in the consortium have to make a step in the direction of other sciences to create those bridges. This involvement requires time, curiosity, and willingness, in order to understand the necessary basics to allow relevant scientific exchange between disciplines. The problem is that this involvement may not result in short term scientific findings in our respective scientific fields, so it may be discouraged due to the emphasis placed on scientific evaluation; it is, however, necessary for such a project to produce added value. The good point is that this interdisciplinary added value is welcomed and appreciated by non-academic partners such as built heritage managers and regional development organizations.

5 Conclusion

The selection of applications presented in this communication makes it possible to assess the potential for tourist development of the VALMOD program. The search for a common ground between architecture, history of built heritage, and 3D acquisition technologies has shown that it is possible to produce original content while maintaining high scientific quality. Whether to illustrate the architecture of the Château de Chambord, physically unscrew the double staircase, or virtually handle stones that are too fragile to be made available to the public, all these initiatives reveal the possibilities opened up by an interdisciplinary approach. The creation of innovative scenarios for tourist development from these examples is still in progress. The next steps will be to benefit from the contribution to other programs of the "Chantier Chambord Château" to build up interdisciplinary interactions and enrich content, and to find appropriate media for dissemination of the results.

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