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Combination of 3D Scanning, Modeling and Analyzing Methods around the Castle of Coatfrec Reconstitution

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Abstract. The castle of Coatfrec is a medieval castle in Brittany constituting merely a few remaining ruins currently in the process of restoration. Beyond its great archeological interest, it has become, over the course of the last few years, the subject of experimentation in digital archeology. Methods of 3D scanning were implored in order to gauge comparisons between the remaining structures and their absent hypothetical ones, resulting in the first quantitative results of its kind. This paper seeks to introduce the methods which carried out said research, as well as to present the subsequent results obtained using these new digital tools.

Keywords: Breton castles, virtual archaeology, 3d scanning, 3d modeling, digital preservation, 3d volume comparison.

1 Introduction

In April 2013, the association which manages the castle of Coatfrec contacted our team, made up of archaeologists, graphic designers and computer scientists, to consider a 3D scanning and modeling of the castle. Over the progression of this project, an idea emerged to combine the all of the produced digital data from the scans, so to provide new analytic tools for archaeologists.

Since the democratization of 3D scanning and modeling technologies, the use of such methods for castles has become common place [5] [6]. Ten years ago, when these technologies were still in their relative infancy, the archeological importance of such monuments, scattered across Europe, inspired their early adoption and utilization [7] [8]. From a general archeological viewpoint, the evolution of these techniques to produce 3D data [12], projects [14] [15] and teams [11] now allows for the development of more complete analysis and simulation of 3D structures which might better respond to complex archeological query [13]. From this supposition, we'll begin by presenting the archeological context of the site, followed by an overview of

the 3D scanning and modeling conducted by two teams at different times. We will then explore how 3D analysis was used to answer specific archeological questions. Finally we'll conclude by discussing this project, and briefly touching on future work.

2 Archaeological Context

2.1 History

The castle of Coatfrec is located in the department Côtes-d'Amor (northwest France) to the east of the town Ploubezre and southeast of Lannion, on the western bank of the small coastal river Léguer. Its name is as obscure as its origins, as even today it is uncertain whether it is called Coatfrec or Coëtfrec. Originally, it was built as a fortress to overlook the winding Léguer, its hills, and its densely wooded and sparsely populated valley. Its role was to prevent the intrusion of enemy combatants whenever war occurred. The first mentions of the family name Coëtfrec and their lordship appear simultaneously with the foundations of the castle in the 14th century. It was during this period that the castles surroundings were burdened by the War of Breton Succession, and towards the end of the century, Jeanne de Coëtgourden and her husband Alain de Kerimel strived to restore the castle [1] [2]. By the end of the 15th century, the castle reflected other military architectures of the time. A letter written on the 7th of August 1462 by François II, the duke of Brittany, stated he feared war with Louis XI and thus sent to the castle two of his officers. Their task, if possible, was to repair the existing fortifications and to raze them if they found them irreparable, but they found them sound enough to allow for the restitution of the castle's walls. In 1589, the French Wars of Religion extended throughout the territory. In Brittany, members of the Catholic League led by the duke of Mercoeur opposed to members loyal to King Henri III. At the same time, the Lord of Kergomar joined the royalist cause and decided to restore the castle of Coatfrec. He began by digging moats, raising the parapets of the entrance, built artillery rooms and stockpiled various weapons and ammunitions. After he demolished farmhouses and leveled the grounds. In 1592 the duke of Mercoeur instructed Guy Eder de la Fontenelle, an infamous brigandier nicknamed "Ar Bleiz" ("the wolf" in Breton), to capture the castle. He did so, without any bloodshed, then upgraded its fortifications, installed a strong garrison and pillaged the countryside all the way to Lannion.

In the end, royalists of Kergomar and Sourdéac besieged the castle of Coatfrec in 1593. La Fontenelle capitulated and the castle was destroyed. Then it was abandoned and served thereafter mainly as quarry for nearby residents [3].

2.2 The Archaeological Site

The ruins of the castle today represent an area of 1700 m² encircled by a 4m deep moat. To the southeast a 30m high tower adjoins the "Grand Logis", a residential wing dating from the 15th century (fig 1). A structure composed of few rooms with 20m high chimneys, kitchens and the bread oven is located west of the site. This part

is connected by the north to the gatehouse, dating from the late 14th or early 15th century, by a complex of walls which shows signs of numerous modifications. To the east, a wall dated after 1462 connects to a residential tower with the gatehouse to its north. This wall exhibits three crenellations with loopholes and wooden beams below them assigned to a parapet walk. Each of these elements indicates that aggressors had a relatively limited point of contact.



Fig. 1. Photos of the ruins: eastern tower, southern wall and the "Grand Logis"

3 3D Scanning

Initially, the process of 3D scanning the castle of Coatfrec was motivated by two specific goals: to prohibit further degradation of the monument, as well as to assist the association responsible for the preservation of the site by providing a more complete reconstruction of its parts. Therefore a team constituted of archaeologists, professional climbers and surveyors from German companies ("Laserscan Berlin", "denkmal3D", Vechta, "Moscito Seiltechnik", Heidelberg and "Rope Access Solutions", Bremen) came twice to France. In 2007, a team covered 90% of the site with the scanner in ten days. The last 10% was measured in 2012 and included mural crowns, parts of the tower, the crenellation and the cistern, which is over 12 m deep (fig 2). The laser scanner used in 2012 could measure 500,000 points per second, its range of accuracy was within a few millimeters with a maximum range of around 79m. After scanning, generated pictures were added to the existing point cloud in order to create a photo-realistic 3D model on which each stone and other details might be viewed at close range. This point cloud further assisted in producing a map of the current state of the ruins. The greatest challenges to the process proved to be the weight of the scanner at 15kg, rain, and overgrowth. But thanks to the assistance of the association of the castle of Coatfrec, the project was a success [4].



Fig. 2. 3D scanning of the castle

4 3D Modeling

The idea here was to model the castle using a combination of plans, sketches and discussions with archaeologists produced independently of the 3D scanned data from the current ruins. Resulting 3d model rendering is presented in Fig 3.

4.1 Northern and Southern Front

The section to the northern front proved rather curious for the team of archaeologists. After modeling was complete and proposals were offered as to potential approximate volumes representing two towers with a linking block, a debate between archaeologists was born. The first hypothesis, formulated by an archaeologist using a 2D plane, suggested the presence of a porch building forming a separate “châtelet”, supported by a turret with a spiral staircase, and surrounded by two nearly identical towers. Recent considerations, supplemented by the 3d scanning in 2012 as well as aerial imagery, revealed rather the presence of a large square tower attached to the drawbridge and a smaller tower slightly further behind it. Regarding the north structure, it continues all along the width of the castle and serves as support for the western residential wing. According to the latest suggestions mentioned above, it is unclear that there was ever a homogeneous “châtelet”, whereas the entrance seems indeed to have undergone several successive developments.

The southern front forms a more coherent structure: the two towers and the central body had certainly a uniform horizontal movement of traffic at floor and wall-walk levels. Despite the lack of remains which had formed the west tower, it was decided to render the towers framing this great residential building symmetrically. Window locations are still subject of discussion, but the modeled proposal seems likely with regard to the existing remains.

4.2 Western Front and Eastern Curtain Wall

The rear western buildings are more contemporary in design meaning that their ridgepoles were adjoined to themselves. A hexagonal staircase tower, reminiscent to that of Suscinio castle, also stands behind the large residential building to the southwest. A question regarding its linked wall-walk is ongoing and it would eventually be relevant to render it covered by a furring strip overlapping the building's edge. To the other side, there is also uncertainty about the coronation curtain wall but archaeologists believe that battlements and parapets were of the same type as those of the castle of Combourg. A set of three latrines is hung to the corner of the curtain wall and the large south-east tower.

4.4 Related Structures

Two different types of chimneys were scattered over the roofs of the castle. On the northern front, it would seem to be the same model as the la Roche-Jagu castle used.

Other chimneys look more like those of the Hac manor. Their locations were identified by archaeologists. Regarding machicolations on the whole, their appearances correspond most closely to the Breton pyramid-shaped types with their spacing being the same as those of the castle of Fougères.

4.5 Digital Elevation Model

In order to produce a mesh of the surrounding castle grounds inclusive in particular of the the moat, two solutions had been considered: to build a mesh from the point cloud resulting from laser scanning or directly use a mesh from a ten years old topographic survey. This last solution was adopted because the mesh is not very dense and untouched by any intrusive vegetation. It was thus easy to handle and it required just a simple vector smoothing to obtain satisfactory results. This topographic survey was conducted in 2005 by civil engineering students and was commissioned by an archaeologist. Two total stations Leica TC1100 and TC705 were used for the survey; isometric curves and a mesh were generated using the Covadis software and were easily imported through 3DSmax with great assistance of the model's .dwg file format.



Fig. 3. 3D renderings showing northern and western parts surrounded by ground and moat

5 3D Analysis

A principle advantage of combining scanning and modeling is the ability to compare a site's hypothetical reconstitutions with its existing parts. In order to garner the maximum benefits from these complimentary data, we choose to utilize two methods: the Meshlab Hausdorff distance method as well as a 3d volume calculation.

To mix existing and hypothetical data within the same 3D model, so to have a visual comparison, our first approach was to simply superimpose the point cloud over the modeling. The problem of this approach is that the point cloud can cover up modeling in certain areas and vice versa. The Meshlab Hausdorff distance tool [10] avoids this problem because it allows a representation of the modeling textured with a color gradient defining its differences with the cloud (fig 4).

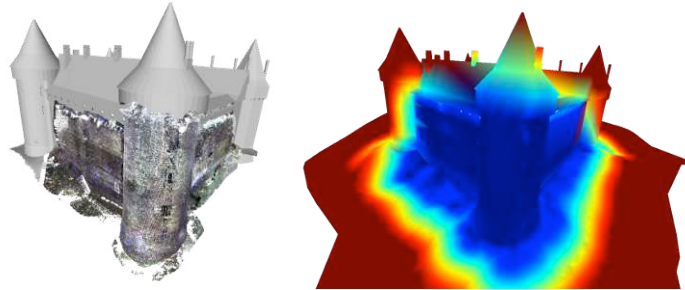


Fig. 4. 3D renderings showing cloud and modeling glued together (left) and the modeling textured with a color gradient illustrating its distances with the cloud (right)

In an attempt to both discover the volume of lost remains of the site as well as to pinpoint areas of particular interest to excavate, we sought to estimate the volume of “hypothetical material quantity”; i.e. the sum of the volumes of the absent walls, roofs and related structures. First our point cloud had to be cleaned and put through a Screen Poisson Reconstruction [9] with a depth of 8. We then filled the blanks of the resulting mesh and calculated its volume using MeshLab (Compute Geometric Measures). The result, as they corresponded to the existing remains, was 3561.27m^3 .

To generate a mesh corresponding only to the hypothetical parts, we developed an algorithm that subtracts the point cloud from the mesh by removing mesh points inside the cloud's radius (see below for a simplified presentation of the algorithm). It uses the “radiusSearch” function from Point Cloud Library (PCL) which searches for all the nearest neighbors of the query point in a given radius.

Overview of the subtraction algorithm

```

PC = {x, y, z ∈ ℝ} // Input Points Cloud to remove
M = (MP, MF) // Input Mesh
MP = {x, y, z ∈ ℝ} // Mesh points of M
MF = {a, b, c ∈ MP} // Mesh faces of M
Radius ∈ ℝ*+ // Input Radius for search precision
var Ptr = {p ∈ MP} // Points to remove

for each P in PC //Find points to remove
    Ptr = Ptr ∪ radiusSearch(kdtree(MP), P, Radius)

for each F in MF
    for each P in F
        if P ∈ Ptr then MF = MF - F
MP = MP - Ptr

```

To convert the model in a thick and closed mesh, without going through an additional modeling step, we finally applied a solidify modifier on the resulting mesh with Blender software (fig 5). Because we only focused on the volume of the castle, we

tried to remove the maximum of polygons corresponding to the ground. We obtained a volume, corresponding to the hypothetical parts, of 6686.23m³. The volume ratio between the existing structures and the hypothetical ones added to them was 34.8% ($3561.27/(3561.27+6686.23)$).

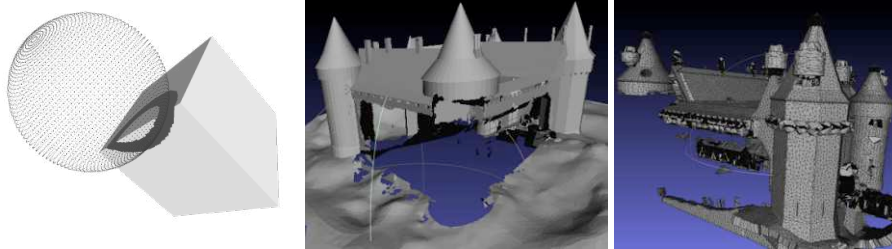


Fig. 5. Left to right: Detection of faces to delete during an algorithm test, application of the algorithm on castle model and point cloud without and with solidify modifier

6 Discussion

The volume estimations described above provided an interesting metric for on-going discussions and further analysis. Because the thickness of the walls weren't equal for every part, we used an approximate average value indicated by the archaeologists and applied that average over the entire building: 1.50m. Moreover, the solidifying modifier we used was then applied to the roofs, which obviously should be considerably thinner than the walls.

Even if the work is quite significant, it would have been appropriate in the first place to divide the model into parts of equal thickness, in correspondence with specialized archaeologists for each structural type (walls, frames, roofs etc.). Then, we could apply the solidifying modifier to each parts corresponding thickness value.

The point cloud was cleaned of polygons representing the ground, but not entirely, in part because of the rich complexity of some areas. A low wall was also removed from the cloud because the "Screened Poisson Surface", with low resolution, turned it into a mass of non-exploitable polygons. This addition and subtraction of polygons must certainly have distorted the overall volume comparison.

The methods, these initial results and visualizations appeared however to be particularly interesting for the archaeologists studying the site. And we believe that this "wear ratio", if the calculation is improved and achieved within a stricter framework, could eventually be used in the field of heritage conservation. This framework, thanks to its quantitative aspects, would allow for better identification of sites "in danger" as well as to estimate their evolutions and degradation rates.

3D scanning and modeling are today widely exploited, not necessarily by archaeologists themselves, but at least by specialists in these techniques gravitating towards the archeological and research communities. 3D digitization of existing structures allows analytical approaches to increase democratization of projects which entail in particular the restoration of sites. We tried, through the example of the castle of Coatfrec, to combine digitization of existing along with the reconstruction of hypothetical to quantify their differences and commonalities.

7 Future works

Future works shall involve principally a continuation of the castle modeling, in collaboration with the archaeologists. This will entail finishing general volume estimates, texturing the models and beginning to propose suggestions for its interior. A rethinking of the evaluation of various elements thicknesses will then be done to achieve a more accurate estimate of the missing volumes. Due to the current change of proprietorship of the castle, no new scans are currently scheduled at this time.

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