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Computerised Geometric Analysis of a Spire Coming from a Gothic Tabernacle

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Abstract. This article focuses on fragments from a spire which belong to the upper part of a Gothic tabernacle. The aim of the paper is to present and evaluate techniques providing us with different kinds of geometric information from 3D models and 2D shapes of cross sections of such fragments, and to show how computerised tools can be used to classify and analyse this material. Further, these tools could be seen as a pre-process for reconstructing a complete Gothic spire, and may help to build up a database. The latter may give access to specific fragments coming from a wide collection of items by querying the database with geometric criteria.

1. Introduction

In 1991, archaeological excavations in the floor of the choir of the collegiate church of Brussels, Saints Michel-et-Gudule (now cathedral Saints Michel-et-Gudule) revealed 11600 fragments of stone sculpture dated to 15th and 16th centuries (Bonenfant 1998). According to archaeologists, they belonged to different monuments, probably located around the choir. Although no description was known to them, the excavators have already attributed pieces to a Gothic rood-screen, a Gothic tabernacle and a Renaissance niche through a careful stylistic analysis.

Among this material, there is a group of fragments considered to come from a Gothic spire. The latter is a distinctive feature of Gothic architecture which occurs on public and religious building but also on smaller size construction such as tabernacles. The number and size of our preserved fragments show that they belong to this latter category.

When studying this material, archaeologists examine closely the moldings (drawing and measuring them) and compare them with other preserved pieces in order to build up stylistic groups. This process is long and tedious, and in our case, fragments are carved in soft white stone, raising conservation problems which limit their handling. That is why, computerised tools were developed to improve the different steps of this analysis.

2. Previous Work

No former study on moldings involving computerised tools is known to us. Yet, a similar approach was taken in several pottery studies: a 2D curve draws the profile of a shape and allows a classification process.

On this topic we may mention classification systems based either on segmentation of profiles (Sablatnig 1998, Razdan 2001), or on definition of a function describing the profile (Karasik 2003). Following theses studies, we would like to classify the moldings of the spire.

3. 3D Acquisition

The 3D acquisition of the fragments is the first step to start with. It allows us to work on virtual representations which facilitate the analysis and avoid deteriorating the material. For this purpose, highly accurate 3D models are needed since the level of detail on the fragments must be less than one millimeter. Moreover, due to the fragility of the fragments, the 3D acquisition system should use a non-contact technique. Taking into account these constraints we had chosen a system based on laser strip triangulation, and we used the 3D scanner FastSCAN, commercialised by Polhemus (Polhemus website). According to their interest, 30 fragments were selected to be scanned. You may find an example of both fragment and 3D model in Fig. 1.

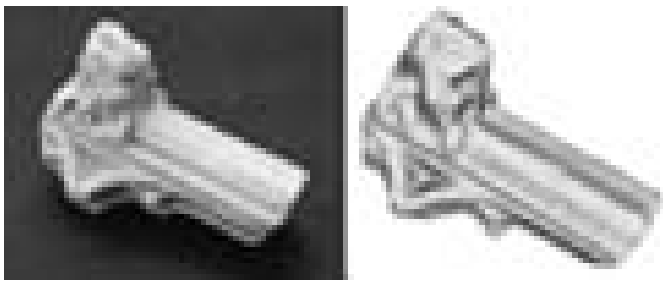

Fig. 1. Example of an archaeological fragment (left) and its virtual representation (right).

4. Orientation of the Fragments

The analysis of the fragments starts with the search of a valid orientation. In our case, by valid, one means an orientation which follows the elongated parts of the fragments. Although several methods already exist to define the orientation of an object, such as PCA (Gonzalez 1992), its extensions (weighted vertices (Vranic 2000), barycenters (Paquet 2000), continuous PCA (Vranic 2001)) and moments of inertia (Novotni 2001) (based on dynamics of rigid bodies (Meriam 1993)), they do not work when applied on our fragments (see

Fig. 2(a–e)). This is mainly due to the presence of outliers (crockets). We therefore had to develop a new approach to define a more valid orientation.

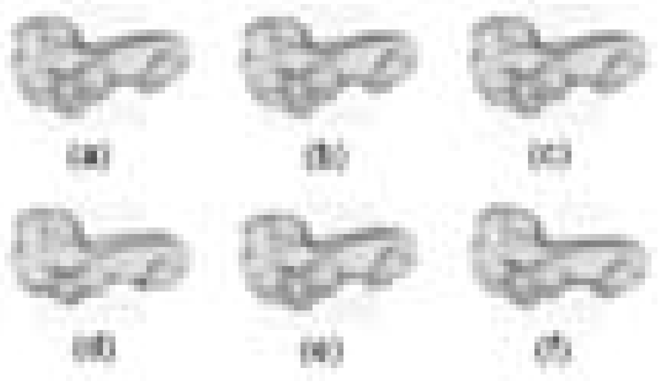

Fig. 2. Orientations of a fragment obtained by (a) PCA (b) PCA with weighted vertices (c) PCA with weighted barycenters (d) continuous PCA (e) moments (f) our method based on study of curvatures.

By computing differential parameters (do Carmo 1976) on the surface of the 3D model, it is possible to select elements belonging to straight ridges, straight ravines and their respective direction. By counting all these directions and related them with a potential orientation for 3D model, we were able to select the direction which appears most frequently and which helps identifying the elongated part.
This method was applied automatically on the 30 fragments and gave satisfying results for most of them (an example is given in Fig. 2(f)), while few fragments needed to be corrected a little to obtain a visually satisfying orientation.

4. Extraction of the Moldings

In order to extract the molding of a fragment, we cut its model in a plan perpendicular to the orientation previously found and we select a slice where the crocket does not occur. An illustration of this step is given in Fig. 3.
While this step could be completed automatically by defining a criterion identifying a part of the fragment where a crocket does not occur, we did it manually to guaranty the efficiency of the procedure for the 30 fragments.

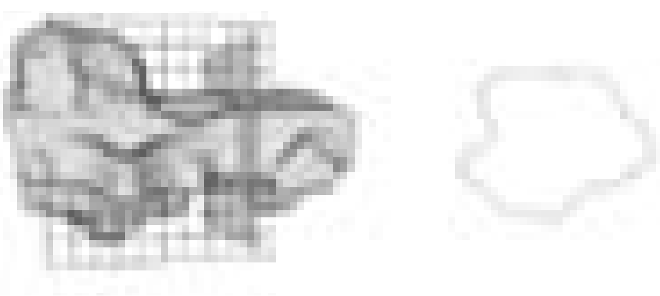

Fig. 3. Extraction of the molding: fragment cut by a plane visualized by its intersection with the model (left) and resulting cross-section (right).

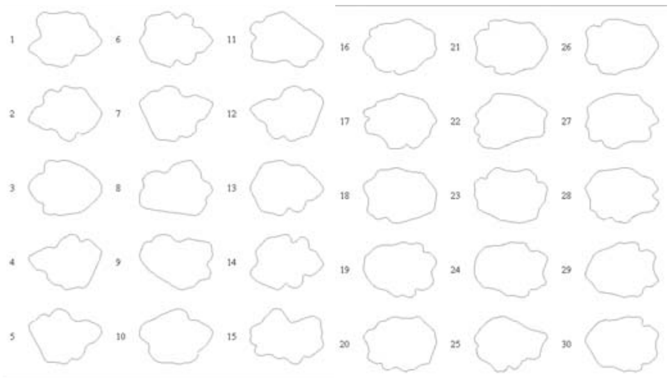

Fig. 4. The sets of moldings we worked with: set 1 with different moldings (left) and set 2 with similar moldings identified by the archaeologists (right).

5. Aided Classification

The moldings we obtain define two sets: One with moldings of different shapes, and another with similar shapes defining a class already identified by archaeologists (Fig. 4).
These data should lead to a classification of the molding as automatic as possible in order to build up relevant classes. Yet, several problems have to be faced : we ignore the number of different moldings, and there is no prototype for each existing molding. We, therefore, propose a classification made in a supervised way. For this, we visualized a distribution of the molding in a space where similar moldings produce easily identified concentrations. To create this distribution, we compute a value quantifying the degree of similarity for each pair of moldings. We use these values to generate a distribution in a 2D space by using a MDS (Multi Dimensional Scaling) (Kruskal 1964).
In order to compute these values, we evaluate different distances (a good survey of distances can be found in (Veltkamp 2001)) applied on point sets (Hausdorff's distance (Alt 1993), EMD (Rubner 1998)), polygons (Fréchet's distance (Alt 1995), turning function (Arkin 1991)), and areas (Area of symmetric difference (Alt 1996)). When the distances between the moldings are known, we visualize their distribution with a MDS (Multi Dimensional Scaling) to identify classes. For this, we used an existing MATLAB routine (website routine). In this paper we provide only with the most significant results in Fig. 5 because of space restriction.
The general results show that distances based on polygons and signature on polygons are not efficient when moldings are mixed (result obtained with the turning function is shown in Fig. 5). This is mainly due to the fact that signatures we used are not robust against noise. On the other hand, distances based on point sets and areas are more stable and provide with easily identified concentrations to distinguish between the two sets (cf Fig. 5). According to the different visualizations generated by MDS, concentrations identify similar moldings and provide with an acceptable basis to select manually the relevant classes of moldings.

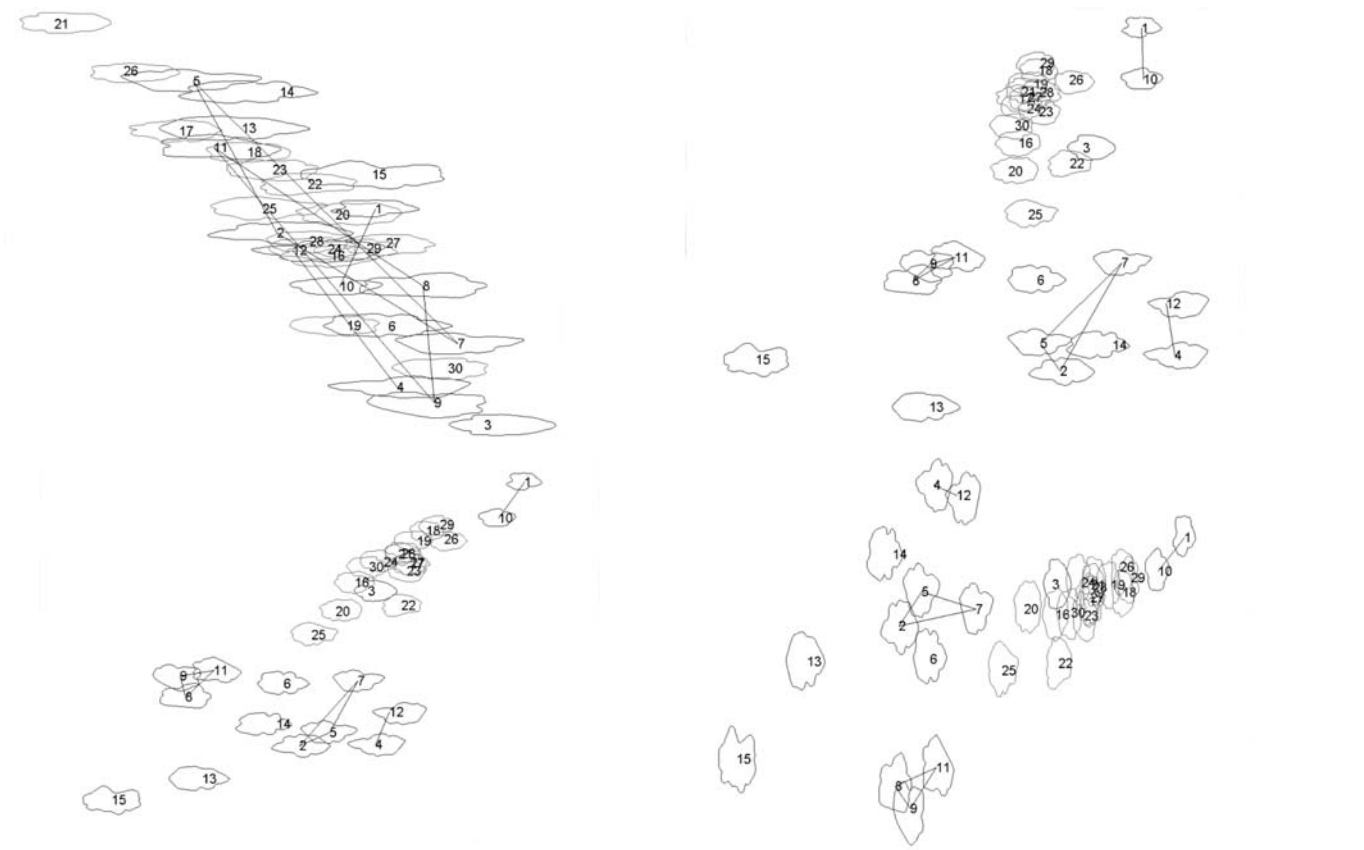

Fig. 5. MDS applied with the distances between the moldings computed with the turning function (upper left), Fréchet's distance (upper right), EMD method (lower left) and areas of symmetric difference (lower right). The straight lines are added manually to connect similar shapes belonging to set 1.

6. Conclusion

In order to help archaeologists in their work, this paper developed and validated computerised tools for the study of architecture which is not usually computationally aided. These tools combine techniques in order to find an valuable orientation, define and classify archaeological fragments with an interesting accuracy in a supervised way.

In the future, we would like to analyze an increasing number of fragments and to automate the classification step. This should allow us to build a typology of moldings which will improve comparative studies with other fragments or preserved architecture.

Acknowledgements

This work is partially supported by the "Région de Bruxelles-Capitale".

Moreover, the authors would like to thank A. Tsingarida for the final reading.

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Website of Polhemus:
http://www.polhemus.com/.
Webiste of the routine MATLAB for MDS:
http://www.psych.indiana.edu/msteyver/downloads/mdszip.zip