Proceedings of the joint international event 9th ARQUEOLÓGICA 2.0 & 3rd GEORES, Valencia (Spain). 26–28 April 2021

Received: 23/11/2020
Accepted: 27/02/2021

ALGORITHMIC MODELLING PROCESSES IN SCAN-TO-BIM WORKFLOWS

Raffaele Argiolas

Department of Civil and Environmental Engineering and Architecture, University of Cagliari, Via Marengo 2, 09123 Cagliari, Italy.
raffaele.argiolas@hotmail.com

Abstract:

The benefits brought by the application of the BIM philosophy to built heritage are now widely recognised, so much so that a closely related methodology, Heritage BIM borned. The HBIM finds practical confirmation in the so-called Scan-to-BIM processes; the data of architectural organisms, in the form of point clouds, are the basis on which the modelling of information is developed, to arrive at geometric models within which all the information necessary for the reading and interpretation of the architectural artefact as well as for its preservation and management is collected. In the paper some of the problems that arise from the application of the Scan-to-BIM processes to complex historical elements are analysed, particularly related to the phases of creation of three-dimensional models. In addition, a reasoning is made about how such problems can be solved or at least mitigated, thanks to the use of algorithmic modelling; the aim is to parameterise the generative process of the models, when the model itself cannot be parametric. In order to do this, a classic typology of historical architecture was examined: late-gothic vaulted systems.

Keywords: HBIM, algorithmic modelling, scan-to-BIM, geometric rules, late-gothic vaults

1. Introduction

In the Scan-to-BIM workflows, at the base of HBIM methodology (Murphy, McGovern & Pavia, 2009), we can identify as the main purpose the transition from survey data to 3D models (Fig. 1); these models must be suitable to be enriched with the multidimensional information characteristic of the BIM philosophy. The main criticalities can be detected especially in the interpretation phase of the survey data, almost always represented by point clouds, and in their transposition into three-dimensional models. The management and processing of point clouds is still a highly time-consuming and resource-intensive process, as evidenced by the numerous studies aimed at the automation of these steps (Liu, 2016; Amano & Lou, 2016). But while in some cases, for elements with relatively simple geometries, the results obtained by the algorithms for recognising architectural components have given excellent results (Macher, Landes, Grussenmeyer, & Alby, 2014), in the case of particularly complex geometries the process proves to be much more difficult (Andriasyan, Moyano, Nieto-Julián, & Antón, 2020). This can be attributed not only to the geometric complexity of the elements, but also to their enormous variety of declinations; this makes it more problematic to identify characteristics that allow precise recognition of shapes. The same factors influence the modelling phases, since complex historical elements often represent unicum that are difficult to reuse in different case studies or contexts; among the causes we can identify the excessive rigidity of the tools for parameterization and modelling of objects within BIM environment. If it is possible to obtain sufficiently complex models, this would in any case require excessive processing time (Aubin, 2014). Therefore, the use of modelling tools external to BIM environments is often necessary. Finally, it should be remembered that the identification of the components in the segmentation phases of the point cloud and modelling is essential to preserve the hierarchy of architectural elements. This is particularly important for the understanding of the architectural organism, both as regards its spatial organisation and construction techniques. The final model must therefore maintain the subdivision but also the correlations of the various components.

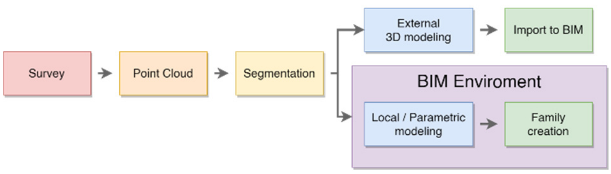

Figure 1: Standard Scan-to-BIM workflow.

2. Methodology

Algorithmic modelling is a technique of generating 3D models by executing an instruction algorithm; specifically, the Dynamo extension of Autodesk Revit software has been used. Dynamo use a visual programming language (VPL) that allows the development of algorithms through a flowchart structure and/or a dedicated scripting language (DesignScript). The advantages offered by this type of tools is, in addition to the possibility of keeping the entire process within the BIM environment, to allow parameterization upstream of model generation.

This means that, unlike standard parametric modelling, a model is not offered with parameters associated with it for subsequent modification, but the parameters are changed before the model is generated. For greater clarity, imagine that it is necessary to adapt a family (how variants of a typology are called in Revit) to a specific case study; this family will offer a predetermined number and type of parameters imposed according to a "basic" model, and therefore cannot be modified except by acting on the model of the family itself. Moreover, the parameterisation tools offered by the BIM environment often do not allow excessive nesting of parameters. If, for example, you want to create a series of n objects, if n is variable, the objects must all be the same; if, on the other hand, you want different objects, their number must be known and fixed in advance. In algorithmic modelling, the initial number of parameters itself becomes a variable; the simple parsing of a string, for example, allows the input of an unfixed number of variables. In addition, the automatic repetition of the entire process each time the parameters are changed makes the nesting of the parameters executable without any problem. Finally, it should not be forgotten that geometric modelling is only a part of the operations that can be performed from the VPL environment, which also include information modelling tools, as well as the possibility of interacting and modifying elements already present in the BIM project, or managing the dialogue with external software and data sources.

Though, since the generative flow is based on an algorithm, it is essential to identify instructions, geometric rules, which lead to the creation of the desired model. The hypothesis underlying the research is that such rules can be deduced from historical treatises, by virtue of the enormous importance that the so-called "geometric rule" has had in the history of construction (Capone & Lanzara, 2019). These rules are evidently linked to the category of elements analysed and not to the single object or context; consequently, the characteristic of reusability of the algorithm, as provided for by the BIM methodology, becomes evident. A single algorithm can, when the initial parameters deriving from the survey vary, generate multiple models, automating a large part of the process. Moreover, the algorithm, developed on the same "instructions" historically used for the definition of shapes, allows not only to preserve the hierarchy of the elements but also the rules: it becomes in fact metadata of the model itself, as it describes its geometric genesis.

It is interesting to note that such an approach to modelling offers interesting perspectives also regarding the phase of extrapolation of information from the point cloud. If in the classical methodology the segmentation of the point cloud is necessary from the beginning for the definition of the shapes to model, starting from the identification of the type and therefore of the geometrical rules that govern it, it is possible to hypothesize a more targeted extraction of the information. If the geometric rule establishes an arc is monocentric, and this is reflected in a wide range of cases, then it is sufficient to derive a few points from the cloud to determine this arc and no longer the whole profile. Furthermore, if the model thus obtained proves capable of representing the real object with a small and stable margin of error, then it can be thought that the model itself becomes an aid to segmentation; segmentation that once performed makes the analysis of the point cloud easier, more easily automated and more specific. A typology of common historic elements not natively managed by the most BIM software, but strongly linked to geometric rules, is that of vaulted systems. The research examines vaulted systems belonging to the so-called late Mediterranean Gothic, a category with a rich historical treatment and with many suggestions on which to work for the definition of geometric rules. In this phase, the research focused on the development of modelling algorithms regarding panels only; as extended elements, panels allow a wide representation of geometries and a greater possibility of error verification. Given the vastness of available treatises, it has been decided to begin the development of the algorithm with what is universally recognised as one of the earliest examples of an attempt to define a geometric rule related to Gothic vaults: Villard de Honnecourt's Rule of the Three Arches (1230).

3. Method application and early results

The method described has been applied to several case studies concerning some churches in the city of Cagliari. The paper presents two particularly significant cases: the vault covering the presbytery in the Church of "*Santa Lucia*" and the system on the main nave of the Church of "*La Speranza*" (Fig. 2).

(a) (b)

Figure 2: The case studies: a) Church of "*Santa Lucia*"; b) Church of "*La Speranza*"

The vaulted systems studied present two types of complexity: geometric or configuration. The geometrical complexity is that found in the systems of five gemstone vaults, typical of the late Gothic period; the complexity of configuration is instead determined by the presence of cross vaults flanked by further portions of cross vaults, specifically a system composed of a cross vault flanked by two half-vaults.

The first step was to develop an algorithm strictly conforming to the "ideal" model obtained from the treatises. As already said for the first phase of development, it was decided to follow Villard's three arches rule (Fig. 3).

In all the case studies the same workflow was followed, which can be summarised in the following steps:

- Identification of the case study and the type of element to be analysed;

- Survey by laser scanner and obtaining the relative point cloud;
- Cleaning and first segmentation of the clouds;
- Geometric analysis and identification of the references / minimum parameters necessary for the application of the geometric rules derived from the treatises;
- Development or implementation of the modelling algorithm, according to the variants found on a case-by-case basis, so that all the declinations can be managed by a single algorithm;
- Generation of models and their validation by computation of model - cloud distances through CloudCompare software.

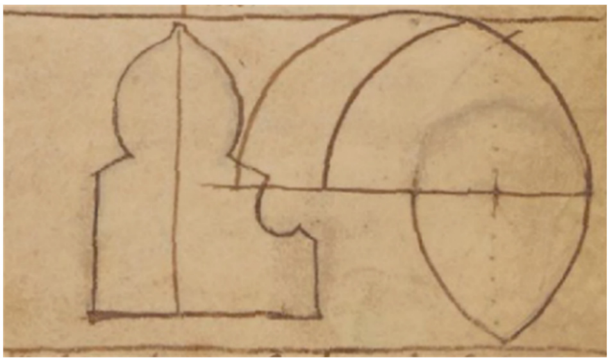

Figure 3: Villard de Honnecourt, the three arcs rule (1235).

Validation is necessary because it is essential to verify the correspondence of the model with the real object, but also to be able to quantify the order of magnitude of the error in the various cases.

The distance computations result for the stellar vault in the Church of "*Santa Lucia*" are shown in Figure 4. As we can see from the results, already from the application of relatively simple geometric rules such as the one proposed by Villard, the errors for the modelled components are particularly small, generally below a few centimetres.

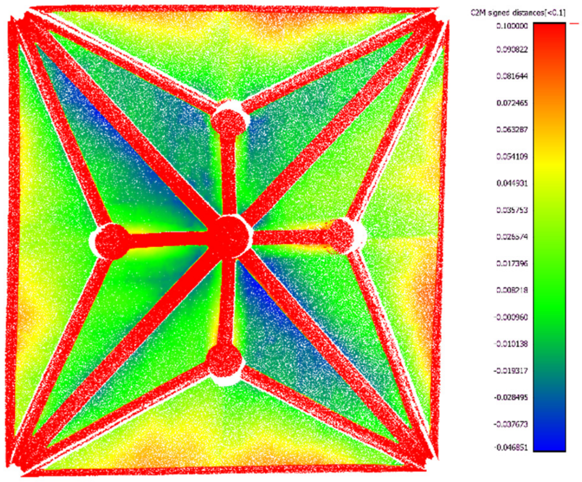

Figure 4: Model – cloud distances computation.

What has been obtained so far therefore seems to confirm the help that the proposed method can provide in the extraction of data from point clouds and their transposition into three-dimensional models.

The future phases foresee a widening of the cases analysed for a better definition of the algorithm; it may also be interesting to apply the same method basing the algorithm on more complex geometric rules, such as those suggested by Curioni in his "L'Arte di Fabbricare" (1865).

Finally, the algorithm is currently being completed for the implementation of the remaining main components of the vaults: the ribs and the bosses.

References

Amano, K., & Lou, E. (2016). BIM for existing facilities: feasibility of spectral image integration to 3D point cloud data. *MATEC Web Conf., 66*, 00024. https://doi.org/10.1051/matecconf/20166600024

Andriasyan, M., Moyano, J., Nieto-Julián, J. E., & Antón, D. (2020). From Point Cloud Data to Building Information Modelling: An Automatic Parametric Workflow for Heritage. *Remote Sensing, 12*(7), 1094. https://doi.org/10.3390/rs12071094

Aubin, P. F. (2014). *Renaissance Revit: creating classical architecture with modern solfware*. G3B Press.

Capone, M., & Lanzara, E. (2019). Scan-to-BIM vs 3D ideal model HBIM: parametric tools to study domes geometry. Int. *Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W9*, 219-226. https://doi.org/10.5194/isprs-archives-xlii-2-w9-219-2019

Curioni, G. (1869). *L'arte di fabbricare: Geometria pratica applicata all'arte del costruttore, lavoro ad uso degl'ingegneri, degli architetti, dei periti in costruzione e di quanti si trovano applicati alla direzione ed alla sorveglianza di costruzioni civili, stradali ed idrauliche, utile agli studenti delle scuole di applicazione per gl'ingegneri e dei corsi tecnici pei periti in costruzione.* Negro, A. F. (Ed.). Torino, Italy

Honnecourt, V. D. (1230). *Livre de portraiture*. Paris National Library.

Liu, Y. (2016). Robust segmentation of raw point clouds into consistent surfaces. *Science China Technological Sciences, 59*(8), 1156-1166. https://doi.org/10.1007/s11431-016-6072-8

Macher, H., Landes, T., Grussenmeyer, P., & Alby, E. (2014). *Semi-automatic Segmentation and Modelling from Point Clouds towards Historical Building Information Modelling*. In: Ioannides M., Magnenat-Thalmann N., Fink E., Žarnić R., Yen AY., Quak E. (Eds) Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. EuroMed 2014. Lecture Notes in Computer Science, vol 8740. Springer, Cham.

https://doi.org/10.1007/978-3-319-13695-0_11

Murphy, M., McGovern, E., & Pavia, S. (2009). Historic building information modelling (HBIM). *Structural Survey, 27*(4), 311-327. https://doi.org/10.1108/02630800910985108