Proportions, Constraints and Semantics for a Parametric Model

Nexus Network Journal (2023) 25:S333–S340
https://doi.org/10.1007/s00004-023-00667-7

Nexus Network Journal
Architecture and Mathematics

CONFERENCE PAPER

Proportions, Constraints and Semantics for a Parametric Model

Massimiliano Lo Turco[1] · **Andrea Tomalini**[1] · **Jacopo Bono**[1]

Accepted: 8 March 2023 / Published online: 24 March 2023

Abstract
An approach to digitally model the decorative elements window's of architectural heritage—the College of Nobles, Turin—in HBIM, by applying De Luca's method. The strategy is to transform them into mathematical ratios and parameters in order to create flexible and adaptable models that can generate variations.

Keywords College of Nobles · Historical treatise · Shape grammars · Proportional analysis · Geometric analysis · Modeling

Introduction

Historic buildings are essential to our cultural heritage, requiring careful conservation and restoration. The use of digital technologies pursuing different objectives, between preservation needs, documentation and intervention proposals, has greatly facilitated this process, creating geometrically and informatively accurate three-dimensional models. In the field of Cultural Heritage, the HBIM (Heritage Building Information Modeling) methodology used in the digital modeling of openings and the decorative apparatus related to them involves translating built elements into geometric/mathematical relationships and parameters. This approach allows the definition of flexible and reusable models that can be easily adapted to any variation of the existing decorations. At the regard, the topic concerns the windows of the College of Nobles in Turin, where the opening combines with a

✉ Jacopo Bono
jacopo.bono@polito.it

Massimiliano Lo Turco
massimiliano.loturco@polito.it

Andrea Tomalini
andrea.tomalini@polito.it

[1] DAD - Department of Architecture and Design, Politecnico di Torino, Viale Pier Andrea Mattioli, 39, 10125 Turin, Italy

complex decorative apparatus to create a distinctive and significant architectural element within this extraordinary baroque building.

The Research

This contribution emphasizes the need of conducting a semantic reading of the recorded data through the geometric interpretation of its forms, within the discipline of Architectural Representation. To achieve this objective, parametric digital modeling was used; in this regard, it is evident how necessary is to reach the definition of the geometric nature of the elements analyzed, to take up the five concepts postulated by De Luca, starting from the treatise: “dominant surface, transition, plans of construction, repetition and moldings”. The following work develops and focuses on this last pivotal point: the molding; thanks to a careful and radical decomposition of the element into “sememe”, the author states that it is possible to understand the components underlying its essence: the geometric primitives. These primitives are compared to the atom—to the smallest physical unit—and through them, it is easiest to comprehend the shape and its combinations, which allow us to reconstruct profiles, surfaces and three-dimensional elements (De Luca et al. 2007: 181–205).

Before delving into the process that led to the definition of the three-dimensional models of the openings and the associated decorations, it is necessary to make an aside about the acquisition of the data used to carry out the study of the shape. The main operation occurred through the metric survey that combined traditional topographic instrumentation (GNSS positioning systems), terrestrial laser scanning (TLS) and terrestrial and aerial photogrammetry. Using this pipeline, a point cloud was obtained with a root mean square deviation (RMSE) from the estimated coordinates of less than 1 cm, verified following least squares compensation calculations. Two sets of orthophotos were generated from the photogrammetric data: the former had an average pixel size on the surfaces of approximately 1.5 mm; the latter had a resolution of 3 mm for easier import and subsequent processing; again, the RMSE value was less than 1 cm. Subsequently, to achieve a correct morphological characterization of the building, the photogrammetric data of the exterior spaces and the LiDAR point clouds were carefully co-registered into a single 3D point cloud with a resolution of 1 cm (Lo Turco et al. 2022). Thanks to this first analysis, it is clear how each architectural element is the expression of three different levels: a first geometric level (lines, curves), a second topological level (parallelisms, concentricity, …), and a third relational level (proportions and harmonic relationships) (De Luca et al. 2006: 160–176).

Using the Representation tools, these three aspects were explored, identifying these typologies’ essential and generative elements. The tools were chosen and used not for the mere purpose of copying/tracing the data acquired during the survey phase. They were rather selected to conduct a phase of active knowledge of architecture, thus generating helpful information. In this sense, Representation constitutes a metalanguage that allows the architectural apparatus to be analyzed more intimately. Borrowing certain concepts derived from structuralism, it is possible to structure the redesigning phase as an activity aimed at understanding the asset: representing the essential parts of the work, eliminating those that do not characterize it, breaking it down into subsets and subsequently recomposing it to understand the relationships existing between the various parts, means recognizing the role of the drawing as a graphic model, as a language capable of interpreting the work. This activity also takes on a theoretical angle, allowing for the elevation of graphical analysis to a critical tool capable of highlighting aspects of the work that would otherwise remain hidden (Docci 2009). Therefore, starting from these initial considerations, it is evident how the survey is not just a mere acquisition, but a knowledge tool, which through the use of re-drawing has allowed the deconstruction of the complexity of architectural elements into elementary units. It has been possible to trace back to every single part populating the HBIM library a molding consisting of a specific profile—the result of geometric combinations, linear and/or curved, concave and convex segments—related to each other according to specific mathematical relationships and functions (Fig. 1).

The Result

Starting from the geometric-mathematical construction of the sub-parts of the elements that make up the decorative apparatus of the windows, it is possible to establish and define the hierarchical relations of the element as a whole which is made up of three main parts:

1. the opening: i.e. the void that subtracts the wall thickness of the built-up building, it comes in square, rectangular, elliptical and polylobate shapes. In each window, it is present two or three times through vertical alignment to the axis of symmetry of the element considered;
2. the window frame: subdivided in turn into a fixed frame (divided into an upper and lower transom and a mullion), a sash (the mobile part of the window, also characterized by a perimeter frame), muntin bars (smaller profiles that further subdivide the glazed part);
3. the decorative apparatus is characterized by a hierarchical structure that differs both along the development of the three floors of the building and at the level of the floor itself, by introducing new singularities and exceptions to the rule of order to which they belong. Briefly analyzing the characteristics of the elements, it is possible to identify:

    a. in the ground floor made up of three openings, there is a molded architrave for the lower opening and the central one, which is enriched below by a sill, while above it is characterized by a simple cornice and triangular pediment, supported by two small brackets;
    b. in the first floor characterized by two openings, the molded architrave is re-proposed with a different course from the previous one, and the logic of overlapping orders is introduced. Within this hierarchical system, two possible registers are identified, denoting a different configuration of the

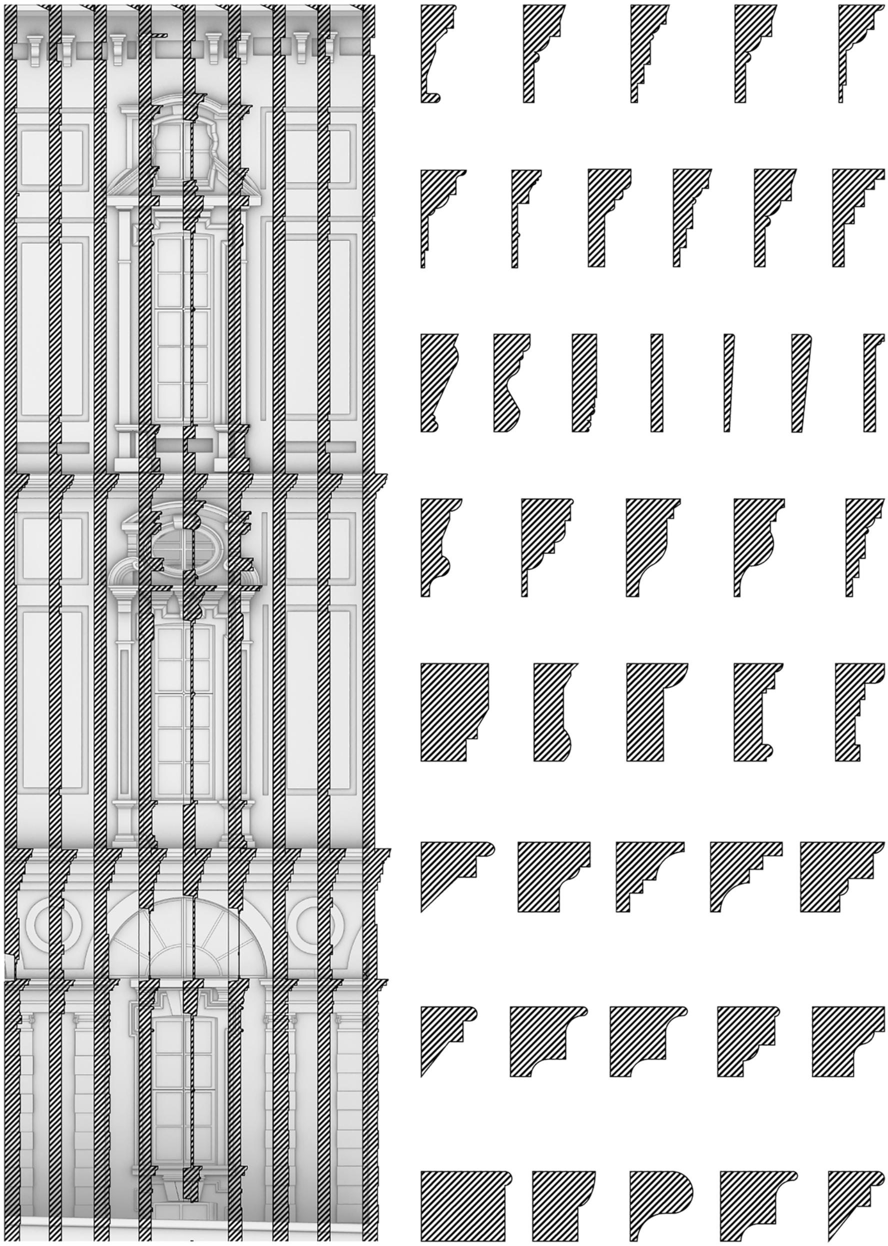

Fig. 1 Geometrical interpretation of forms through the use of cross-sections (general—left) to identify the complexities and specificities of the architectural elements (detail—right) of the College of Nobles. Image: authors

aedicule. Both aediculae consist of pilasters, precisely the lower order of paneled pilasters, which rest on a pedestal and continue in curved brackets supporting different pediments.

The lower aedicula has an open pediment, where the curved cornice is interrupted, forming two 'volutes' for placing a further opening, an elliptical oculus. Instead, the upper aedicula is realized by a segmental broken pediment, where the horizontal element is interrupted between the brackets supporting it;

c. in the second floor, which also consists of two openings, the same 'ingenuity' is repeated with some variations; for the lower aedicula, the open pediment is reused but with a sloping cornice to form two 'wings'. On the other hand, for the upper aedicula, the broken pediment with a linear-curvilinear connotation is reused to insert a polylobate opening, and there is no longer the presence of the supporting brackets (Chitham 2005) (Fig. 2).

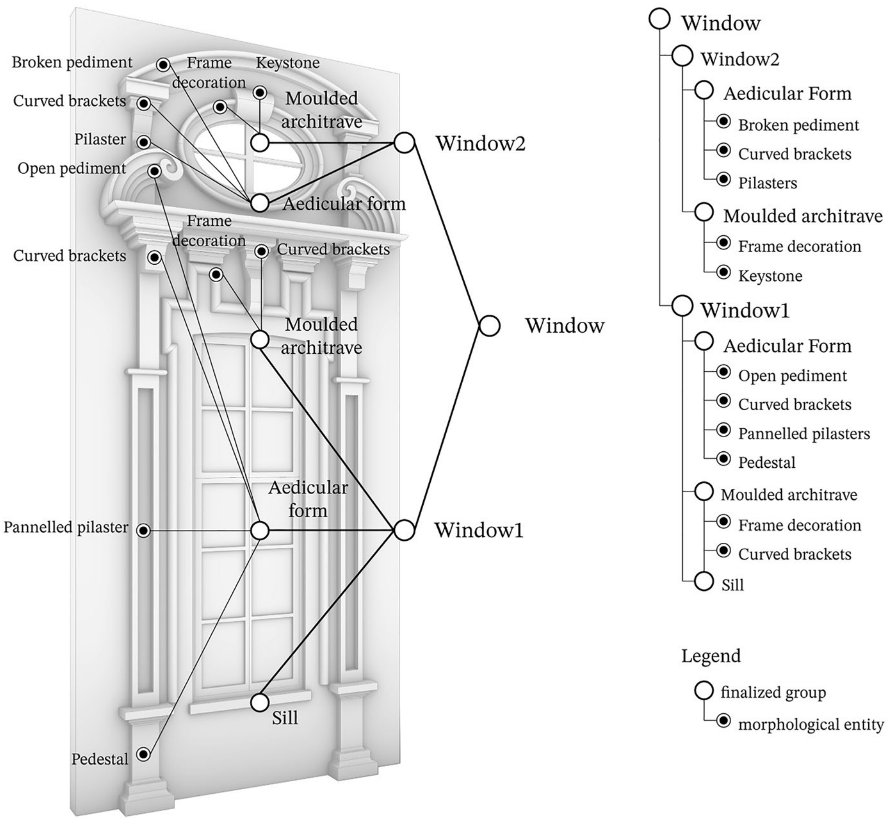

Fig. 2 Analysis and semantic schematization of the elements that make up the decorative apparatus attached to the window on the first floor of the building. Image: authors

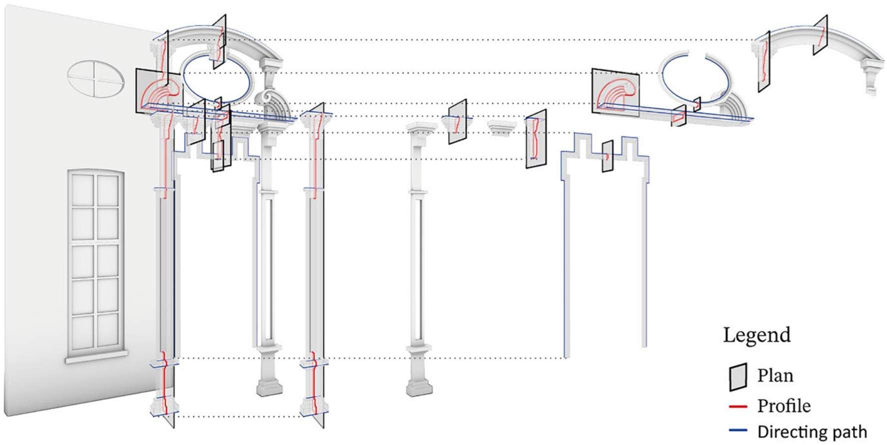

Fig. 3 Reconstruction of the part that make up the decorative apparatus, through the identification of a cutting plane, from which it is possible to extract the profile and through the traditional modelling commands obtain the 3D element. Image: authors

In the light of such a precise subdivision and schematization, it is evident how the proposed approach aims to emphasize the decomposition of the modeling process into atomic phases. This allows reasoning on modules, axes and proportions that can be easily adapted to any modification of the decorations (Fig. 3). For instance, if just one element of the ornaments is changed, only that specific module needs to be updated rather than the entire model. This makes the modeling process much more efficient and flexible.

As mentioned, although HBIM methodologies are ready to acquire data and handle different parameters, it is more challenging to define freeform or complex geometries. For this reason, the research group explored the encoding of geometric parameters in the VPL (Visual Programming Language) environment. In contrast to BIM tools, the graphical elements, such as blocks or icons, typical of VPL tools, encapsulate various programming concepts and allow the user to concentrate on the underlying principles of geometric programming/modeling without being overwhelmed by technical details. Thus, defining the atomic steps to represent these architectures and geometries in a digital representation clearly articulates the relationships between parts (Calvano 2019). Furthermore, continuously updating these systems encourages increasing horizontal interoperability with HBIM platforms, enabling more accurate LOG (Level of Geometry, regulated by norms) standards.

Conclusion

In conclusion, the proposed new approach to digital modeling windows and decorations in the HBIM environment has several advantages. By transforming the constructed elements into mathematical ratios and parameters, flexible and adaptable models can be defined and easily updated to give back the different singularities that characterize a complex decorative apparatus. Furthermore, the subdivision of the modeling process into atomic steps allows to define efficient and easy-to-work modular models by identifying variants and invariants. The research aims to develop this approach further, creating even more transversal digital models by pursuing higher levels of abstraction, employing VPL modeling methodologies and then translating these geometries into the HBIM environment, thus obtaining geometrically and semantically rigorous elements. This level of abstraction, briefly described through some early examples, allows for greater efficiency in managing complexity at the geometric level, and streamlines the processes of computerizing the element itself in the HBIM environment.

Acknowledgements Although the contribution was conceived jointly, M. Lo Turco is author of paragraphs "Introduction" and "Conclusion"; A. Tomalini of paragraph "The Research" and J. Bono of paragraph "The Result".

Funding Open access funding provided by Politecnico di Torino within the CRUI-CARE Agreement.

Data Availability Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Calvano, Michele. 2019. *Disegno digitale esplicito. Rappresentazioni responsive dell'architettura e della città.* Rome: Aracne editrice.

Chitham, Robert. 2005. *The Classical Orders of Architecture*. London: Routledge.

De Luca, Livio, Vèron, Philippe and Florenzano Michel. 2006. Reverse engineering of architectural buildings based on a hybrid modeling approach. *Computers & Graphics* 30(2): 160–176. https://doi.org/10.1016/j.cag.2006.01.020

De Luca, Livio, Vèron, Philippe and Florenzano Michel. 2007. A generic formalism for the semantic modeling and representation of architectural elements. *The Visual Computer* 23(3): 181–205. https://doi.org/10.1007/s00371-006-0092-5

Docci, Mario. 2009. *Disegno e analisi grafica.* Bari: Laterza.

Lo Turco, Massimiliano, et al. 2022. Representing and managing change: the development of H-BIM to refunctionalized the Egyptian Museum in Turin. In *3D Modeling&BIM. Information & 3D Modeling per il patrimonio costruito*, eds. T. Empler, A. Caldarone, E. D'angelo, A. Fusinetti, 160–179. Rome: DEI s.r.l. Tipografia del Genio Civile.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Lo Turco Massimiliano Ph.D., Full Professor ICAR/17 at the Department of Architecture and Design (DAD) at the Politecnico di Torino. He conducts research in the field of digital architecture survey and modeling. He has been dealing for years in analyzing the capabilities of Building Information Modeling and Visual Programming Language applied to Cultural Heritage. Principal Investigator of the BACK TO THE FUTURE project, developed with the Museum of Egyptian Antiquities in Turin, to define new methodologies in which Information Modeling tools can be used unconventionally, to create 3D databases of small objects, particularly those belonging to extensive museum collections. Program Director of the Bachelor's Degree in Architettura/Architecture of Politecnico di Torino since 2018.

Tomalini Andrea architect and Ph.D. Student in "Architectural and Landscape Heritage" with a curricula in drawing and representation. In 2019 he graduated with honours in architecture at Politecnico di Torino. During his Ph.D. (2020–now) at Politecnico di Torino, he is specializing in digital acquisitions, three-dimensional and information modeling. His interests are related to the disciplines of drawing, survey and digital representation of architecture with particular attention to the use of BIM and VPL methodologies for the management of existing assets. Regarding heritage management, he is conducting research to connect the museum and its collections in a single digital environment by developing interoperable processes between different disciplines.

Bono Jacopo Ph.D. student in "Architectural and Landscape Heritage" at Politecnico di Torino, Department of Architecture and Design (DAD). In 2021 he graduated with honors in Architecture Construction and City (ACC) from the Politecnico di Torino. During his postgraduate period, he won two research scholarships: the first entitled—"Phygital Exhibition. Technical support for the setting up of the new area of the Passion Museum of Sordevolo at the Church of S. Marta"—and the second one entitled—"the Modeling of an H-BIM model of the Egyptian Museum". Both experiences focus on drawing, surveying, virtualization, digitization, and modeling of Heritage. Specifically, his research interests concern modeling in the H-BIM environment by investigating the construction of parametric and non-standardized libraries.