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Parameters, Modeling and Taxonomy for an HBIM Baroque Facade

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Abstract

This contribution explores the application of the BIM methodology in the context of built heritage (HBIM). Specifically, it investigates how this methodology has evolved in terms of modeling techniques, viewed through the lens of Drawing as a critical aspect of its implementation. By considering these perspectives together, the paper aims to identify the primary advantages and limitations of HBIM, highlighting the need for defined workflows to effectively manage and deconstruct the intricate architectural elements found in the *Palazzo del Collegio dei Nobili*, which represents Turin's brick buildings from the Savoy Baroque period.

Keywords HBIM · Collegio dei Nobili · Baroque facade · Shape grammar · Heritage elements · Brick

State of the Art

The growing role of Historic Building Information Modeling (HBIM) in the field of built heritage is supported by extensive literature that determines its role, methodology, and trends. BIM applied to built heritage focuses on understanding its construction history and related conditions to facilitate its preservation and management.

> *Each building organism (both repeatable and unrepeatable) corresponds to one and only one piece of construction equipment, i.e. that system, and not*

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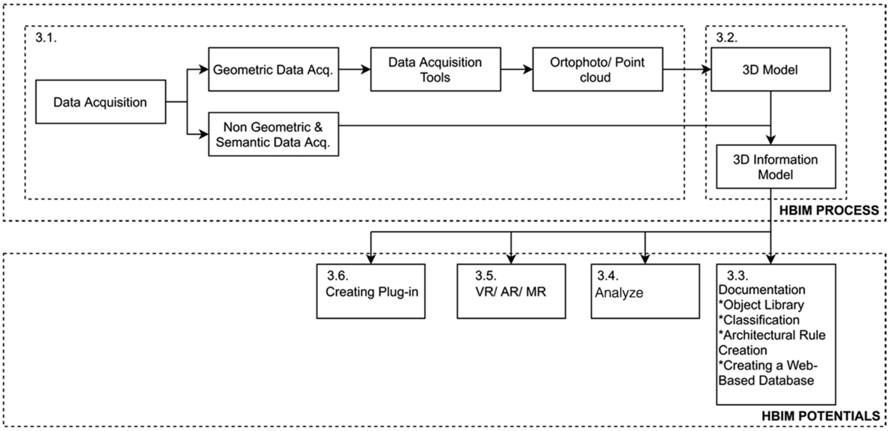


Fig. 1 The declinations of HBIM and its use in the reinterpretation of the facade of the *Palazzo del Collegio dei Nobili*. Image: Bastem and Çekmiş 2021

others, that coherently integrates into the spatial concept that is the raison d'être of the organism itself.[1] (Mandolesi 1978).

The critical analysis of scientific publications on HBIM since its inception in 2009 points out several topics (Fig. 1). These include advancements in:

1. modeling techniques;
2. participatory platforms (such as Virtual Reality, Augmented Reality, Mixed Reality, and web networks);
3. analytical studies (structural and energy aspects);
4. management and monitoring (life cycle);
5. restoration and documentation (photogrammetry and laser scanning) (Hussein and Ismaeel 2020; Bastem and Çekmiş 2021).

This research focuses on modeling techniques, delving into solid geometry modeling to explore architectural grammar, understanding styles, and creating customized parametric libraries (López 2018). Through the lens of drawing, the study reflects on the potentials and limitations of HBIM:

a. The pros refer to the opportunity to translate information into a manageable model for heritage experts, integrating multiple information (semantic, relational, morphological ones), and combining quantitative and qualitative aspects for various applications;

[1] Translated by the authors from the original: «Ad ogni organismo edilizio (sia ripetibile che irripetibile) corrisponde una ed una sola apparecchiatura costruttiva, cioè quel sistema, e non altri, che coerentemente si integra nella concezione spaziale che è la ragion d'essere dell'organismo stesso»

b. The cons include the necessity of defining specific object libraries to take into account the unique characteristics of historic buildings and the related hard challenge of translating 2D/3D geometries into parameters reflecting mathematical and formal relationships.

These features contribute to the multidimensional nature of the digital information model resulting from the HBIM process.

Research Objectives

From its origin to the present, the HBIM approach has assumed different meanings and complementary application fields. However, in most cases, some common phases represent crucial stages in the workflow of this methodology, summarized as follows:

1. acquisition;
2. modeling;
3. sharing.

In the first stage, the goal is to establish the geometry and understand their relationships. In contrast, the subsequent modeling stage, which is the emphasis of this study, focuses on the translation and decomposition of the facade's construction elements within the considered environment.

In contrast, the modeling phase, the focus of this contribution, explores the characterization and composition of the façade's construction elements. The latter phase remains peculiar within the HBIM methodology. It has been one of the earliest features that shaped its identity since its formation in 2009 (Murphy et al. 2009), differentiating it from the BIM approach used for new construction in the AEC sector. Even today, exploring this phase is of great interest, as it presents some peculiar aspects and significant challenges due to the unique characteristics of HBIM's object of investigation -the built heritage. It offers unique elements that cannot be considered identical due to the craftsmanship of construction techniques—the brick—but also the transformations they have undergone over time-inhomogeneities, deformations, and degradations (Brusaporci et al. 2018). While acquisition allows to keep track of these irregularities, it is only through drawing that translates them into geometric-mathematical characteristics. Drawing acquisition aimed at the definition of building components, two-dimensional (2D) and three-dimensional (3D) in nature, capable of being placed within the HBIM environment trough the digital building components.

Due to the peculiarities highlighted above, the building components are the basis of the BIM methodology and are of primary importance in its application in the HBIM environment. The HBIM environment needs the ad hoc realization of non-standardized elements available in the authoring software, capable of accommodating and binding to the geometry-specific parameters that allow

Fig. 2 Decomposition of a building component tailored to fit the unique requirements of the HBIM ▸ environment. It is divided into the geometric aspect (above) and the parametric-informative aspect (below). Image: authors

its flexibility, reuse, and generalization, if not as a whole, in the individual parts that compose it. It is evident the importance of customized building components within this process, which is why we opted for the initial phase of acquisition to analyze and break down the facade into individual architectural components, which can be grouped into macro-groups that can be defined as the stylistic matrix of the Baroque elevation (Sampietro et al. 2018). In their realization, it was decided to investigate one of the aspects that saw the implementation of the interface dedicated to the realization of architectural components, represented by the nesting process, by linking together elements and sub-elements, thanks to 'parameters' that explicit and relate the geometric-mathematical nature constraints of the parts that compose it (Fig. 2).

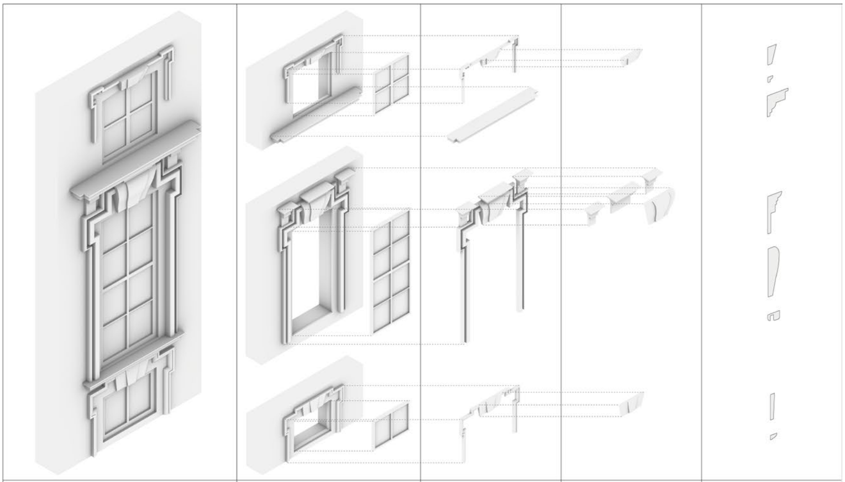
The Process of Digitization of Cultural Institutions: the Case of the *Palazzo del Collegio dei Nobili* in Turin

In the specific case of the digitization project of the *Collegio dei Nobili* in Turin, that houses the *Museo Egizio*, it aligns with the goals of the national plan. The museum has been actively involved in a comprehensive digitization effort for the past few years. This initiative is driven by the dual need to manage and maintain the cultural asset over time effectively and to address ongoing transformational work planned in celebration of the museum's bicentennial.

Five finalist groupings were initially identified as part of the broader international initiative *'Museo Egizio 2024'*, which involved an international design competition. The selected architect for the project is David Gianotten from O.M.A. (Office for Metropolitan Architecture) in Rotterdam. This underscores the museum's commitment to embracing digital advancements and innovative strategies as it progresses through its transformation journey (OMA 2023).

The tender specified that the primary project would involve creating an HBIM model for transforming parts. Dealing with digitizing a historically significant building with intricate geometric/formal complexity presented an opportunity to establish specific workflows for controlling and breaking down complex architectural elements. This involved the use of formulas and numerical parameters by considering variations and constants. Such an approach enables the creation of adaptable and reusable models that can easily accommodate changes in existing decorations. The focus here is on window elements, where the opening combined with elaborate decorations constitute a distinctive architectural feature in this remarkable Baroque building. This element's immediate application and reuse will be tested through a significant international collaboration.

The digital model constructed using the HBIM methodology serves two primary purposes:



Parametro	Valore	Formula
Costruzione		
Chiusura muro	Per host	=
Tipo di costruzione		=
Materiali e finiture		
Davanzale	<Per categoria>	=
Decorazione	<Per categoria>	=
Telaio	<Per categoria>	=
Vetro	Vetro	=
Estremità principale		
INF_CTR_H apertura arco (default)	50.0	=
INF_CTR_H davanzale (default)	30.0	=
INF_CTR_H sottodavanzale (default)	250.0	=
INF_CTR_H telaio mobile (default)	3230.0	=INF_CTR_H apertura -
INF_CTR_L davanzale (default)	250.0	=
INF_CTR_L mazzetta (default)	50.0	=
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INF_CTR_PR davanzale (default)	150.0	=
INF_CTR_PR mazzetta (default)	50.0	=
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INF_CTR_STR inf (default)	100.0	=
INF_CTR_STR sup (default)	100.0	=
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INF_INF_STR sx (default)	100.0	=
INF_SUP_D dec lat_apertura (default)	400.0	=
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INF_SUP_STR sup (default)	100.0	=
INF_SUP_STR sx (default)	100.0	=
INF_SUP_PR telaio fisso (default)	50.0	=
Estremità secondaria		
CR_CTR_D cornice_apertura (default)	350.0	=
CR_CTR_D1 dec lat_apertura (default)	182.5	=
CR_CTR_H2 (default)	800.0	=
CR_CTR_H3 (default)	300.0	=
CR_CTR_L2 (default)	120.0	=
CR_CTR_L3 (default)	575.0	=
CR_INF_D cornice_apertura (default)	150.0	=
CR_INF_H sottodavanzale (default)	120.0	=
CR_INF_H2 (default)	500.0	=
CR_INF_H3 (default)	185.0	=
CR_INF_L sottodavanzale (default)	900.0	=
CR_INF_L1 (default)	300.0	=
CR_INF_L2 (default)	100.0	=
CR_INF_L3 (default)	300.0	=
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FR_L fregio (default)	2400.0	=
FR_inclinazione (default)	30.00°	=
Quote		
Altezza	0.0	=
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INF_INF_H apertura	900.0	=
INF_INF_H apertura arco	50.0	=
INF_CTR_H apertura	3330.0	=
INF_INF_H da terra (default)	200.0	=
INF_INF_L telaio (default)	50.0	=
INF_SUP_H apertura	950.0	=
INF_SUP_H da fregio (default)	500.0	=
Larghezza	1420.0	=
Larghezza approssimativa		=
Altezza approssimativa		=
Proprietà analitiche		
Costruzione analitica	<Nessuno>	=
Definisci proprietà termiche per	Tipo schematico	=
Trasmittanza luminosa		=
Indice di riscaldamento alla radiazione s		=
Resistenza termica (R)		=
Coefficiente di scambio termico (U)		=
Parametri IFC		
Operazione		=
Altro		
Altezza di default del davanzale	800.0	=

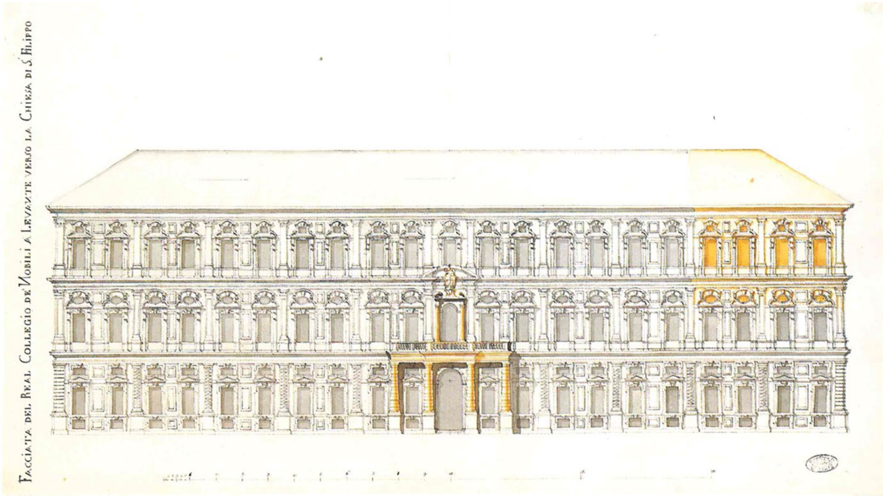


Fig. 3 Architect Carlo Maurizio Vota's facades design. Image: Romano and Dardanello (1993): 120, Corte, *Reali Palazzi*, cartella 4, Torino, Archivio di Stato

1. Assessing the conservation status of the Built Heritage by reinterpreting and understanding its forms;
2. Managing the operation and maintenance of a museum complex with international significance.

The paper aims to delve deeper into the first theme, emphasizing the connection between knowledge and preservation. In this context, HBIM modeling is a valuable tool for three-dimensional archiving and storing information in its parametric repository (Lumini 2021). Its use in this case is essential, given that many European museums are situated within historically significant structures (Valdambrini 2018).

Baroque Factory Rules: Between Geometric and Formal Relations of the Main Facade

The *Museo Egizio*'s headquarters are located in the *Collegio dei Nobili* designed by Carlo Maurizio Vota to convey a celebratory language in court architecture, deviating from Turin's uniform fabric. Michelangelo Garove, a student of Guarino Guarini, executed the design in 1679 (Fig. 3). The building's distinctiveness is achieved through its mass, ornate detailing, and pronounced relief in facade modeling (Romano and Dardanello 1993; Carassi and Gritella 2013).

A preliminary analysis, focusing on facade composition, reveals a general pattern identifiable by understanding the syntax of its elements. In this context, 'syntax' refers to recognizing and comprehending individual parts, as well as their relationships, aimed at respecting and reflecting the Baroque style's original language. The diverse placement and arrangement of these elements on the facade create solutions reminiscent of typical patterns in Turin's architectural typologies.

We can identify two interpretations of the facade system, specifically focusing on the two main axes guiding the composition: the vertical and the horizontal axes (Fasciana 2001; Bo and Casa 2005; Mastrosimone 2022).

Analyzing the facade along the vertical axis (Fig. 4a), it breaks down into four sections:

1. **Basement**: this is the first visible element at eye level, serving as the intersection between the vertical wall and the horizontal street pavement;
2. **Upper facade**: the vertical wall establishes relationships between the external and internal environment, acting as a diaphragm. Baroque-Turin representative buildings typically exhibit two main schemes: (a) three superimposed levels or (b) three levels, two with a giant order, possibly subdivided by mezzanine floors. The *Collegio dei Nobili*, for instance, features numerous mezzanine planes in its elevation;
3. **Cornice**: This is the upper conclusion of the facade, marked by the presence of a closing cornice connecting to the roof;
4. **Roof**: The closing element of the vertical wall, with a sloping or horizontal position.

Alternatively, looking horizontally (Fig. 4b), you can spot the main vertical elements of the previously explored four sections. These elements define and create the intricate texture of this complex pattern, allowing for the placement of plastic and decorative elements—essentially, the openings. Along this axis, the facade's rhythm is determined by regularly shaped carved ornaments and projecting elements resembling classical orders, such as pilasters. These pilasters divide the facade into spans, with the central one (A), which hosts a portal added in a later period, having a single opening and being half the size of the lateral sections (B), each featuring two openings. In summary, the scheme reads as (B-B-B-B-B-A-B-B-B-B).

The synthesis of the facade configuration reveals a distinctive Baroque feature: the symmetry concerning the axis passing through the central span. This axis symbolizes the reversal of the street axis's perspective and scenic axis, maintaining a dialectical exchange between the private inner courtyard and the public city space. OMA's current design for 2024, named the *'agorà pubblica'*, strongly preserves this aspect (OMA—Office for Metropolitan Architecture 2023). Another feature is the ongoing emphasis on the building's central area, hosting the access and representative point, achieved through larger openings, a portal, and adorned with a massive decorative apparatus.

The plastic and decorative elements within this grid reflect the Baroque language (seventeenth-eighteenth century) and reinterpret the codes of the classical orders (Fig. 4c). Works from the period, such as Guarino Guarini's *Trattato di architettura civile* (Guarini 1737) and Bernardo Antonio Vittone's *Istruzioni Elementari per l'indirizzo de' giovani allo studio dell'Architettura*

Fig. 4 **a** Decomposition of the facade along the vertical direction (basement, elevation, crowning and coverage). **b** Decomposition of the facade along the horizontal direction (B-B-B-B-B-A-B-B-B-B-B). **c** Decomposition of the facade in the Baroque plastic and decorative elements (a. basement, b. lesene, c. entablature; d. corner node; e. extrusion/subtraction; f. openings; f.1 portal; f.2 window). Image: authors

Civile (Vittone 1760) point out the cultural climate and the attitude toward reworking classical canons (Vitruvius 1829; Alberti 1546; Serlio 1584; Vignola 1562; Palladio 1570; Chitham 2005).

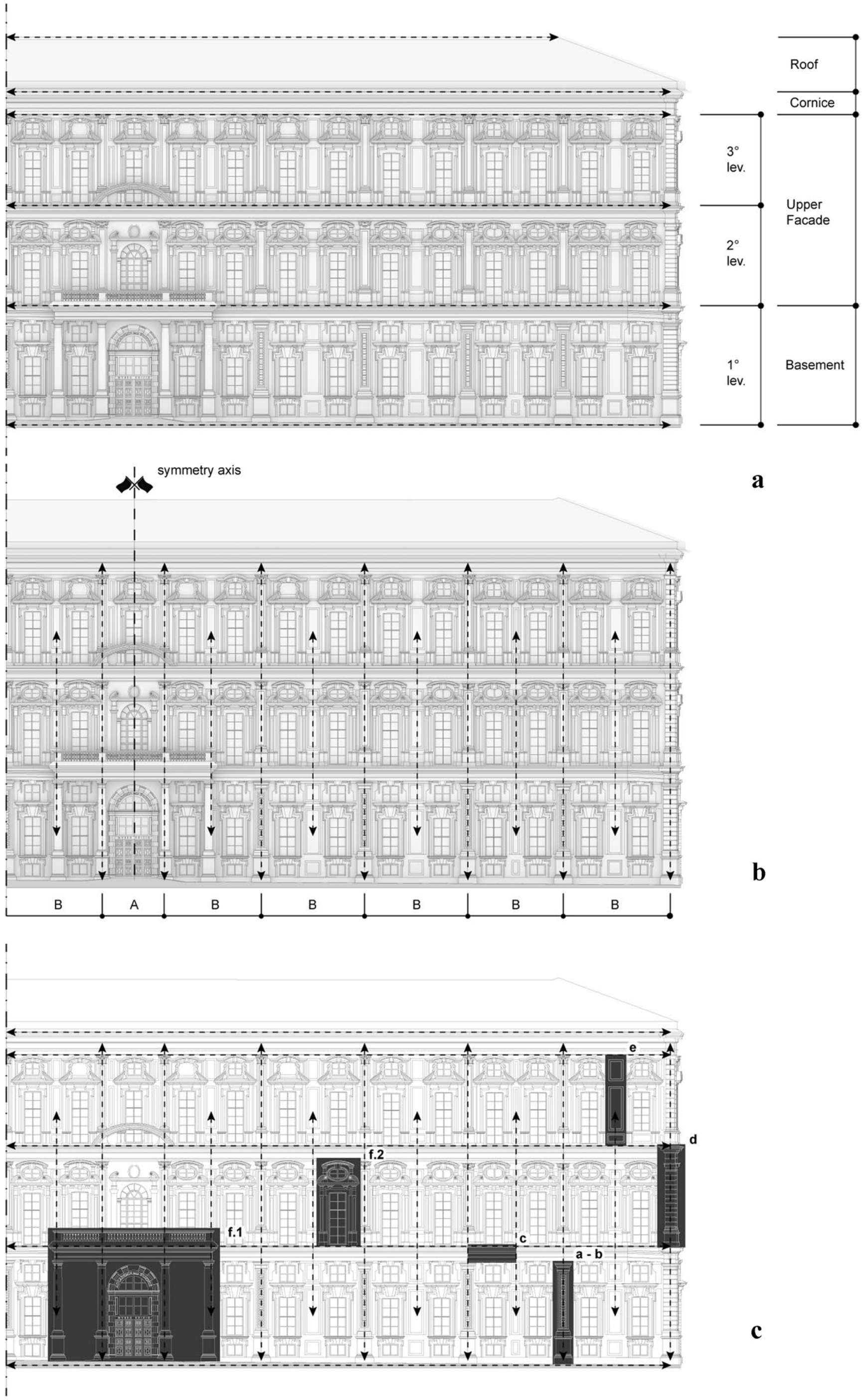
The key elements are summarized as follows.

1. **Basement:** the part's composition is similar to the entire facade, consistently using face brick for projections and indentations across the upper areas. However, it stands out in the structure of its windows, featuring three openings and a rich decorative apparatus around them, along with more detailed pilasters.
2. **Lesene:** These main vertical elements represent the concept of 'order' in the facade's interior and primarily serve as a decorative purpose. They can be divided into three parts:

    a. The **base** in all three registers is positioned above a pedestal and crafted from stone covered with stucco. On the first level, it echoes the elements of the Tuscan base, featuring a single torus and laths. In the second and third levels, it adopts the forms of the Attic base, characterized by two tori interspersed with a scotia following the Ionic (2nd level) and Corinthian (3rd level) orders;
    b. In contrast to classicism, the **shaft** is treated plastically in the Turinese style, utilizing brick to create alternation between voids (openings) and solids (mirrors). In both levels, the element features a rectangular opening as decoration, outlined by stucco. Only on the first level is the subtracted space filled with stucco decoration resembling a truncated pyramid with a square base;
    c. In both the registers the **capital** is placed over the shaft and it is also made of stone covered with stucco. On the first level, the capital has simple moldings reminiscent of the Tuscan order. In the second level, it becomes more complex, introducing the head of a winged putto in the center, with volutes at the ends supporting a festoon (Ionic). In the third level, the capital incorporates floral decorations, with acanthus leaves reminiscent of the Corinthian order.

3. **Entablature:** This is the horizontal element positioned above the pilasters, serving a decorative function, often called the ledge. It can be divided, similar to the vertical pilaster element, into three components:

    a. The **architrave:** is the lower level in contact with the decorative brickwork around the facade openings. On the first and second levels, it consists of a simple, single band, while on the third level, it features two bars separated by a projecting brick lath;


Roof
Cornice
3° lev.
2° lev.
1° lev.
Upper Facade
Basement
a
symmetry axis
b
B
A
B
B
B
B
B
e
d
f.2
f.1
c
a - b
c

b. The **frieze**: Positioned between the lintel and cornice, this intermediate level is more complex and articulated, reminiscent of classical architecture. On the first level, it exhibits the alternation of metopes and triglyphs using brick, while on the second/third level, it appears as a band framed at the ends by laths;
c. The **cornice:** is the uppermost level, serving as the concluding part of the entablature. The first level features alternating smooth bands with more excellent extrusion. On the second level, inspired by the Ionic order, it is adorned with alternating dentils. At the third level, the decoration changes, following the Corinthian order and characterized by alternating modillions and carved corbels.

4. **Corner Node:** this is a noteworthy feature in the Baroque style, emphasizing the urban significance of the building as a cohesive element for its facades. Like pilasters and their order throughout the entire facade, the corner node follows the same principles. To ensure the continuity of the elevations perpendicular to each other, the two pilasters are connected without perfectly intersecting, creating a groove. The distinction from the facade pilasters lies in the use of stucco material and the inclusion of ashlar decoration that defines their shaft (Fig. 5).
5. **Extrusion and subtraction elements:** These adornments are situated alongside the openings, typically positioned either above or below, a design choice influenced by full-height windows on the facade. The decorations feature square shapes, creating a visual interplay between solid and void elements.
6. **Openings**: These are the components integrated into the structure formed by the previously mentioned elements. They fall into two categories: windows and portals. In contrast, the window is examined in Guarini's treatise, which outlines the rules for its construction:

> *The first rule is that they must all be the same […] The second is that they must be ordered correspondingly on this side and the other side of the middle […] The fifth is that a frame must always be made around the window, which will make the sides, the uprights or pilasters of the window […] the sixth part of the width of the light will be made, or at most the fifth [… The sixth is that the windows may be adorned in various ways, and first with its frames […] The second is a frontispiece, when above the aforementioned circumferential frame a frame will be made that bears the frontispiece […] The third is in panels and scrolls […] The fourth is in the form of moldings […] which advance outwards and protrude to bear the frame*[2] (De Fusco 2003).

[2] Translated by the authors from the original: «La prima regola sia che debbano esser tutte uguali […] La seconda è che siano ordinate corrispondentemente di qua e di là del mezzo […] La quinta si è che attorno alla finestra si farà sempre una cornice, la quale farà i fianchi, erte o pilastrate della finestra […] si farà la sesta parte della larghezza della luce o al più la quinta […] La sesta è che le finestre si potranno adornare in varie guise, e prima con le sue cornici […] La seconda a frontespizio, quando sopra alla cornice di circonferenza predetta se gli farà sopra una cornice che porti il frontespizio […] La terza è a cartelle e volute […] La quarta è a modiglioni […] i quali si avanzano in fuori e sporgendo portano la cornice»

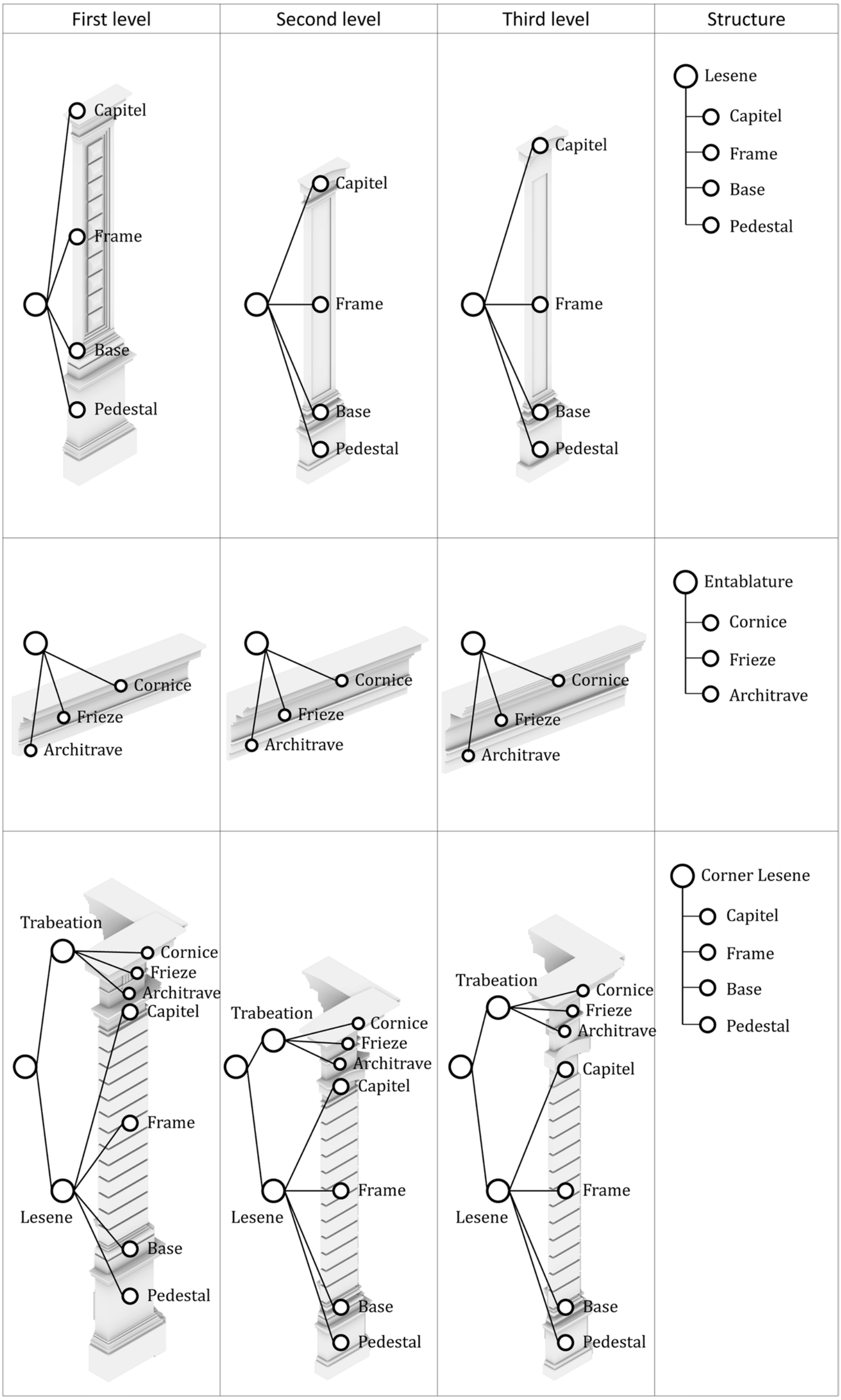


Fig. 5 Analysis and semantic schematization of the elements of the building facade: pilaster, entablature, and corner node. Image: authors

The **windows** of the *Collegio dei Nobili*, like other aristocratic buildings in Baroque Turin, echo various styles of presenting decorative elements associated with openings. One such element that adorns the openings across all three levels is the cornice.

a. The **frame decoration** is characterized by various moldings that facilitate the creation of projecting and intricate decorations near the openings. Surrounding the cornice on the second and third levels are pilasters, vertical elements whose upper ends may feature a sort of 'capital' supporting the pediment or tympanum;
b. The **pilasters**, appearing as minor pilasters with a shaft and capital, or only the latter, exhibit distinctive features on different levels of the *Collegio dei Nobili*. On the first level, this element lacks a shaft but is marked by a 'pseudo-capital' founded with the underlying frame of the opening. A squared bracket represents it. On the second and third levels, these secondary pilasters feature a rectangular shaft outlining its perimeter and a capital. The capital varies in its bracket design; the lower level displays modillions (curved bracket), while the upper level streamlines it through straight lines;
c. The **pediment**, supported by the pilasters, is a fertile ground for architect Garove's ambitions and fantasies in designing the desired forms. It evolves from a simple rectilinear entablature on the first level to more complex ones on subsequent levels. The second level introduces a broken pediment with a curvilinear nature, framed by volutes at the ends, enclosing an upper opening with an elliptical shape. This opening incorporates decorative elements like the cornice, pilasters, and pediment. The third-level openings also feature a broken, linear pediment, 'almost triangular,' encompassing a polylobate upper window decorated tripartite (Fig. 6).

A portal is a feature with its own column order that extends outward from the main facade. This extension serves to project the entrance hall, a pivotal element in the distribution system of the representative building, into the public space. The **portal** acts as a mediator and works as a diaphragm. It is tripartite, with two windows flanking its sides. The key elements are:

a. The **arched fornix** marks the entrance portal to the building and exhibits diverse forms of ferrule;
b. The **rounded Tuscan columns** serve to support the balcony above and enable the overhang, establishing the portal's position related to the facade line (Fig. 7).

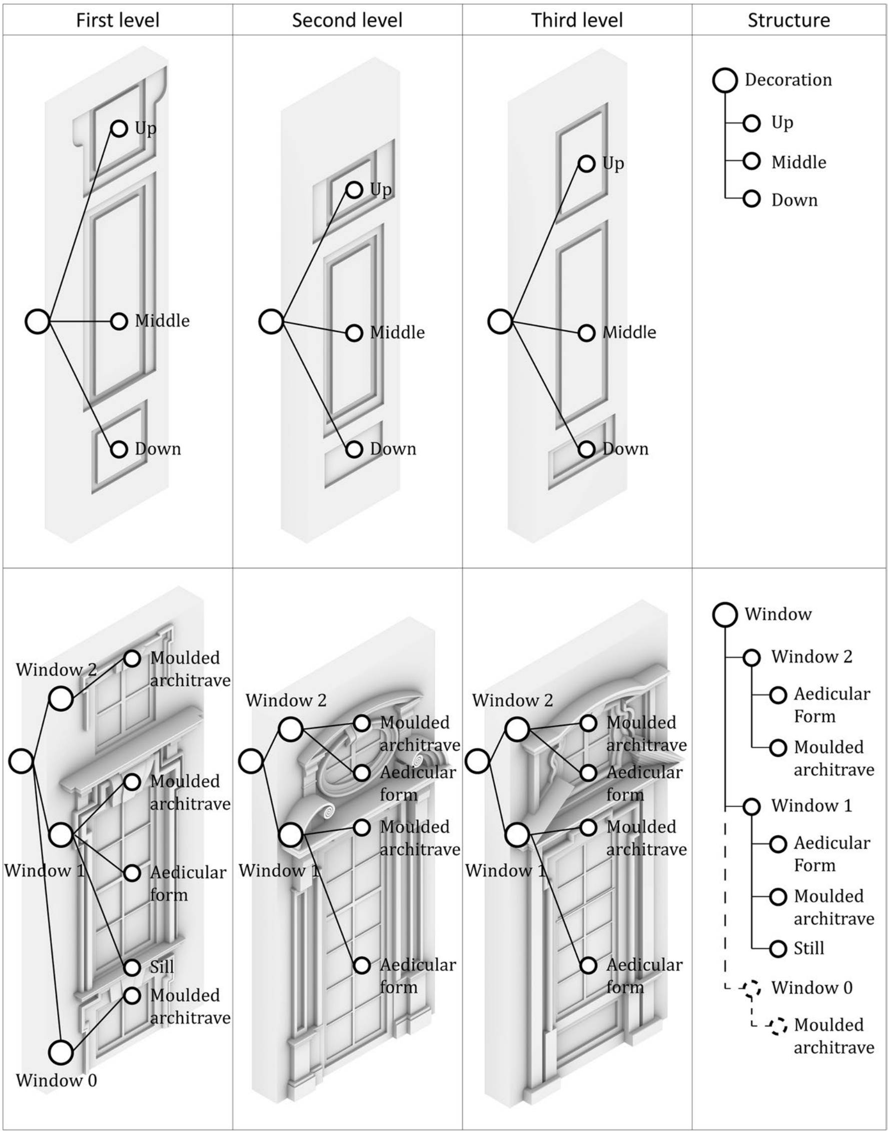


Fig. 6 Analysis and semantic schematization of the elements of the building facade: decoration and windows. Image: authors

The Key Role of Brick in Facade Compositions

The building's structure is technically designed using exposed brickwork. This composition adheres to construction standards and significantly influences the visual perception of these elements. Bricks play a crucial role in shaping these elements' geometric and mathematical relationships.

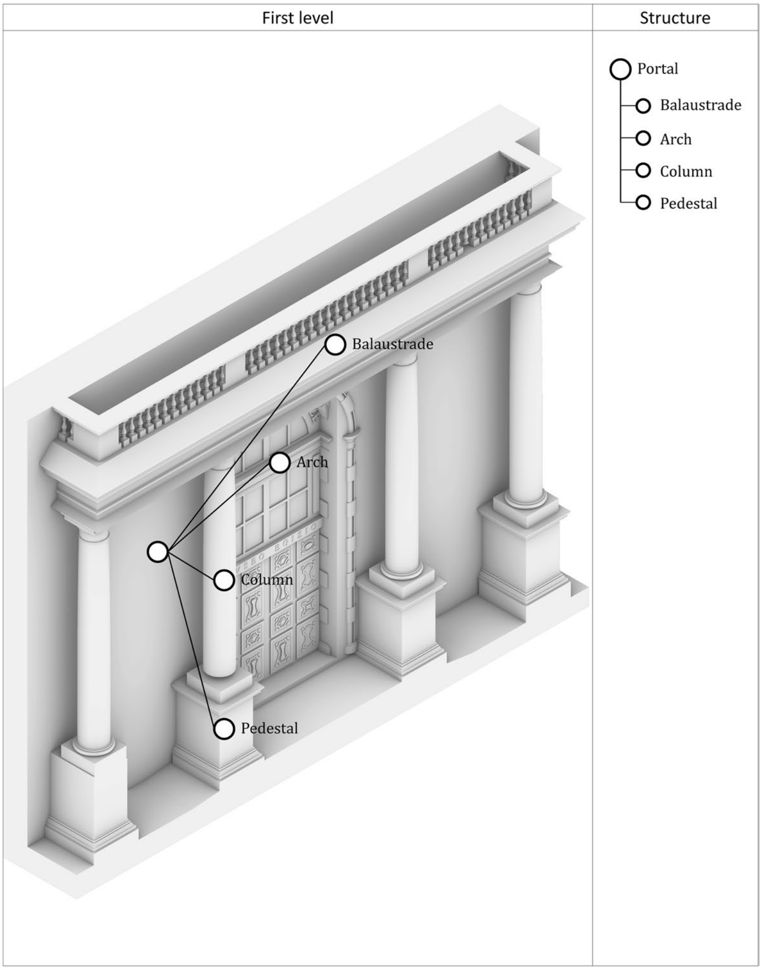


Fig. 7 Analysis and semantic schematization of the elements of the building facade: portal. Image: authors

Brick is one of the earliest standardized architectural elements (Campbell and Pryce 2016), having undergone slight variations in dimensions over time. Their sizes are anthropometric, closely tied to the human body, with their depth determined by the installer's hand size (Lynch 1994: 89–97). Bricks can be categorized based on the analysis of specific variables.

Regarding the case study, we can identify two types of bricks (Fig. 8):

a. **Standard**: These are employed to create regular elements that can be repeated, making them suitable for large-scale use;

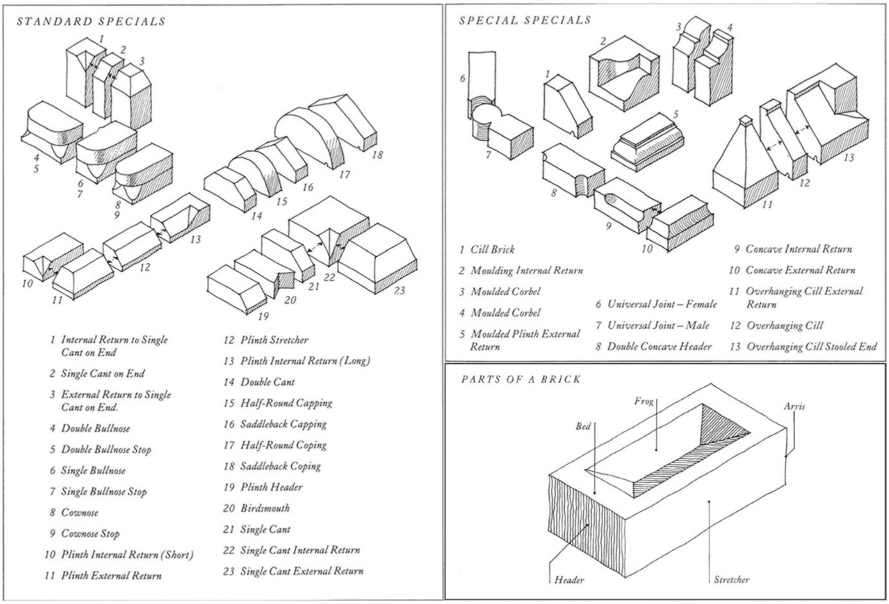


Fig. 8 Different parts of the brick and its proportions, categorized into standard and special bricks. Image: Plumridge 1993:164–170–171

b. **Special**: These bricks craft distinctive and unique elements, requiring processing of the standard type. They are often utilized for aesthetic purposes, such as in cornices and facade windows (Plumridge 1993).

The use and popularity of bricks as a construction material in the architecture of Turin can be attributed primarily to geological factors and the prevalence of construction sites in valley areas, such as the Po Valley, where the city is situated (Roccatelli et al. 1925). In the architectural context, brick applications in building construction in Turin is mainly associated with two specific purposes: as a cladding material for fortifications and as a symbolic element signifying buildings affiliated with the Savoy royal family.

The *Collegio dei Nobili* refers to the latter category. The facade, designed by Guarini's student, employs brick as a sculptural element to evoke the classical architectural orders in the minds of observers. The facade is divided into three registers, each presenting a distinct composition of Baroque orders and windows. Notably, curved bricks arranged in rows form the cornices, providing a distinctive character to this structure compared to other brick architectures in Turin (Xu 2021).

In both levels, the central rectangular window is consistently accompanied at the top by a secondary window, with variations in shape:

a. Ground floor: alternation between square and rectangular shapes (Fig. 9a);
b. First level: oval shape (Fig. 9b);
c. Second level: irregular 'polylobed' shape (Fig. 9c).

Fig. 9 **a** Surface articulation and order drawing of the third level, **b** surface articulation and order ▶ drawing of the second level, **c** surface articulation and order drawing of the first level. Image: Orthophoto: DIATI, layout: authors

The distinctive curved brick frame on the facade embellishes the central rectangular window openings (Fig. 10a). The details include:

a. Ground level: the cornice exhibits greater complexity with two parallel rows of curved bricks separated by a groove. A key element breaks the cornice with vertically arranged bricks, creating a concave-convex surface (Fig. 10b);
b. First and second levels: the cornice is more straightforward with a single row of bricks. The decorative frame around the window is more sophisticated, featuring broken pediments at the upper openings (oval and polylobate).

Elements of the orders are positioned in the areas between windows. Due to limited space, these orders closely relate to and merge with adjacent windows:

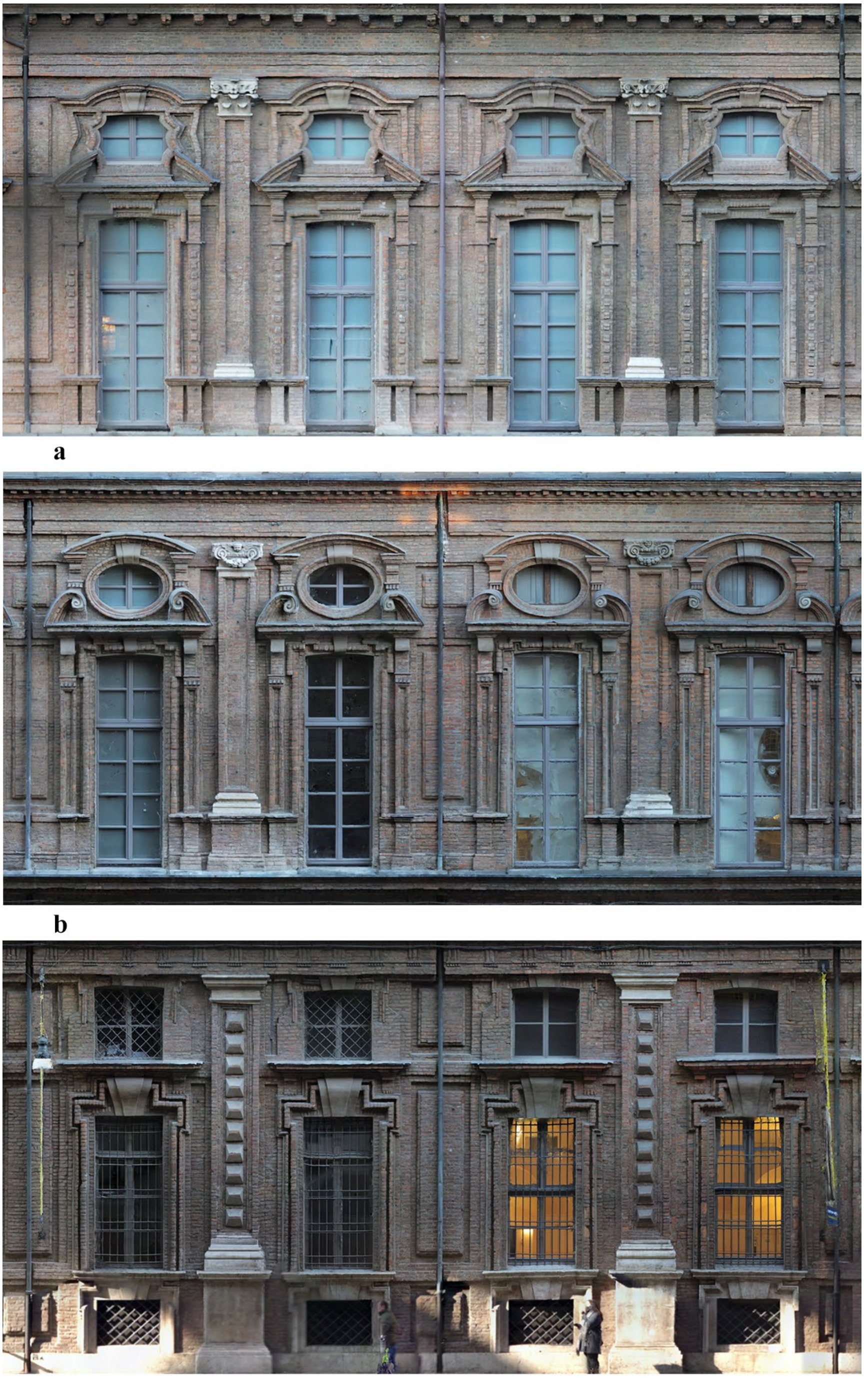
a. Ground floor: the order features a distinctive language, incorporating serial reproduction of decorative elements resembling truncated pyramids with a square base;
b. First and second levels: the order adopts Ionic and later Corinthian styles, reflecting Baroque language variations.

Another element is the presence of rectangular voids adorned with curved brick decorations.

Hence, it is clear that a window is more than just an opening resulting from subtracting a void from a wall; it is a complex entity formed by the simultaneous presence of voids and solids. The interplay between these concepts defines its shape and structure, attributing significant importance to the window as a crucial and integral component of the wall facade. Breaking it down into its fundamental elements (the atoms) and utilizing modeling and Visual Programming Language (VPL) within the HBIM framework allows us to revisit the concepts that guided its creation. This involves employing geometric and mathematical principles to construct the sub-parts of the window and establish hierarchical relationships among them (Luca et al. 2007; Calvano 2019).

Conclusions

Examining Baroque facades, especially that of the *Palazzo del Collegio dei Nobili*, is pivotal for grasping the intricacies and elegance of this architectural style. During the modeling phase there is an opportunity to translate this complexity into building components that reflect the variations and richness of Baroque facades. These architectural elements are designed to meet the prerequisites imposed by the HBIM methodology, which requires identifying and classifying each element



a

b

c

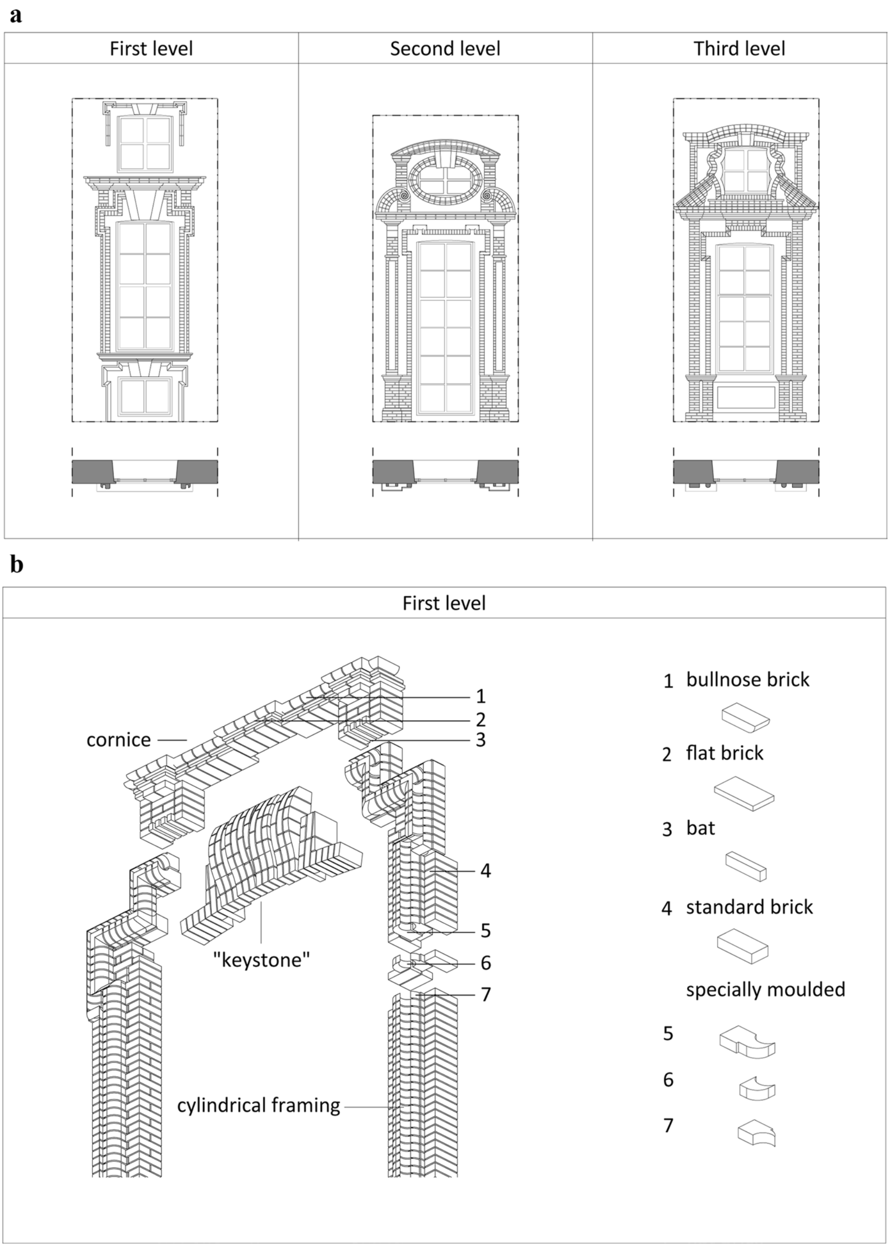


Fig. 10 **a** The main textures created by the bricks of the three windows on the main facade of the *Collegio dei Nobili*. Image: authors. **b** Breakdown of the decorative elements into individual units (bricks) of the ground-floor window on the main facade of the *Collegio dei Nobili*. Image: Xu 2021: 59

through a dedicated taxonomy; allowing them to be assigned a specific degree of representation and information to facilitate thorough understanding. Detailed attention and comprehensive study of the vertical and horizontal scheme of the Baroque facade have enabled the achievement of these goals, as further reduced by redesigning the façade in a 3D modeling environment.

The intricate vertical composition of the palace, comprising the basement, elevation, ledge, and roof, plays a crucial role in shaping the structure. These elements do not stand alone; they interact harmoniously to form a visually and conceptually cohesive whole. In the horizontal arrangement, the positioning of pilasters and adornments contributes to defining the façade's overall structure, highlighting the aesthetic and stylistic features typical of the Baroque period. The strategic placement of plastic and decorative elements, including the basement, lesene, trabeation, corner nodes, extrusion and subtraction elements, follows a deliberate architectural plan. Each element is thoughtfully positioned to create a unified entity communicating a distinctive visual language. Architectural features like portals and windows go beyond mere functionality, becoming integral components that contribute to the overall aesthetic, shaping the style and identity of the building.

The approach to analyzing Baroque facades should not be limited to static observation but can extend within HBIM environments. Understanding the geometric and spatial relationships between architectural elements can be translated into an HBIM environment, enabling an advanced digital representation of the building. This model will not only preserve the visual complexity of the Baroque style, but also opens up new perspectives for study and interpretation. The introduction of parametric families into the HBIM environment enables the development of an advanced methodology for creating and modifying facade elements. The parameterization of the brick, the single essential part of Baroque facades, becomes fundamental. Its versatility allows for all complex aspects, providing the flexibility to explore different configurations and designs. This parametric approach enables dynamic representation of facades, facilitating visualization and understanding of the relationships between elements.

In conclusion, integrating the *Palazzo del Collegio dei Nobili* into Visual Programming Language environments enables the development of novel design and research methods. Visual programming's adaptability facilitates swift exploration of various design possibilities, allowing for testing variations and evaluating both visual and structural effects. This innovative approach to analyzing and representing Baroque facades preserves their historical and artistic significance and deepens comprehension and admiration through advanced technological tools. The analysis of Baroque facades not only enriches our understanding of historical architecture but also opens up new challenges for research and practical application of these sophisticated architectural principles with the incorporation of new technologies.

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Declarations

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

References

Alberti, Leon Battista. 1546. *I dieci libri de l'architettura di Leon Battista de gli Alberti Fiorentino*. Vinegia: Vincenzo Vavgris.

Bastem, Sumeyye Sena and Aslı Çekmiş. 2021. Development of historic building information modelling: a systematic literature review. *Building Research & Information* 50: 1–32. https://doi.org/https://doi.org/10.1080/09613218.2021.1983754.

Bo, Andrea and Norberto Casa. 2005. Apparato decorativo nei prospetti dei palazzi barocchi in Torino. Master's thesis, Politecnico di Torino.

Brusaporci, S., P. Maiezza and A. Tata. 2018. A framework for architectural heritage HBIM semantization and development. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLII–2. Copernicus GmbH: 179–184. https://doi.org/10.5194/isprs-archives-XLII-2-179-2018.

Calvano, Michele. 2019. *Disegno digitale esplicito: rappresentazioni responsive dell'architettura e della città*. Canterano: Aracne.

Campbell, James W. P. and Will Pryce. 2016. *Brick: a world history*. London: Thames & Hudson.

Carassi, Marco and Gianfranco Gritella. 2013. *Il re e l'architetto: viaggio in una città perduta e ritrovata*. Torino: Hapax.

Chitham, Robert. 2005. *The Classical Orders of Architecture*. United States: Taylor & Francis.

De Fusco, Renato. 2003. *Il codice dell'architettura: antologia di trattatisti*. Napoli: Liguori.

Fasciana, Tiziana. 2001. Il palazzo nobiliare barocco a Torino. Il linguaggio architettonico di facciata. Master's thesis, Politecnico di Torino.

Guarini, Guarino. 1737. *Architettura civile, del padre d. Guarino Guarini cherico regolare: opera postuma dedicata a sua sacra reale maestà*. Turin: Gianfrancesco Mairesse all'insegna di Santa Teresa di Gesù.

Hussein, Khlaid and Emad Ismaeel. 2020. State-of-the-art of Historic Building Information Modelling - HBIM Trends in the Built Heritage - Review Paper. *Diyala Journal of Engineering Sciences* 13: 77–90. https://doi.org/10.24237/djes.2020.13308.

López, Facundo José. 2018. *Reconstrucción tridimensional del patrimonio arquitectónico mediante la utilización de los sistemas BIM y HBIM. Validación con dos casos de estudio: la Iglesia Santa María la Real de Mave y el Castillo de los Comuneros de Torrelobatón*. Valladolid: University of Valladolid.

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

Lumini, Andrea. 2021. L'HBIM per la fruizione virtuale interattiva del Patrimonio Architettonico e dei metadati informativi. Il caso studio della Scuola di Guerra Aerea di Firenze. Doctoral thesis, Università degli Studi di Firenze.

Lynch, Gerard C. J. 1994. *Brickwork: history, technology and practice*. London: Donhead.

Mandolesi, Enrico. 1978. *Edilizia. Le finalità, il processo edilizio, l'edilizia industrializzata, l'edilizia del futuro* vol. 1. Torino: UTET.

Mastrosimone, Michele. 2022. H-BIM as a tool for drawing and graphical analysis of the fronts of the Palazzo dell'Accademia delle Scienze and the Collegio dei Nobili. From survey to the reinterpretation of a facade. Master's thesis, Politecnico di Torino.

Murphy, Maurice, Eugene Mcgovern, and S. Pavía. 2009. Historic building information modelling (HBIM). *Structural Survey* 27: 311–327. https://doi.org/https://doi.org/10.1108/02630800910985108.

OMA - Office for Metropolitan Architecture. 2023. Museo Egizio 2024.

Palladio, Andrea. 1570. *I quattro libri dell'architettura di Andrea Palladio*. Venice: Domenico De Franceschi.

Plumridge, Andrew. 1993. *Brickwork: architecture and design*. London: Studio Vista.

Roccatelli, Carlo, Enrico Verdozzi and Gerhardt C Mars. 1925. *Brickwork in Italy: a brief review from ancient to modern times.* Chicago: American Face Brick Assoc.

Romano, Giovanni and Giuseppe Dardanello. 1993. *Torino 1675-1699: strategie e conflitti del barocco*. Turin: Cassa di Risparmio di Torino.

Sampietro, Fabrizio, Maria Masciopinto, Ivan Cincotta, Giacomo Bergonzoni and Roberta Mittempergher. 2018. Computational design in the HBIM process. *3D Modeling & BIM: Nuove Frontiere, Roma,* 318–333. https://www.researchgate.net/publication/334574392_Computational_design_in_the_HBIM_process

Serlio, Sebastiano. 1584. *Tutte l'opere d'architettura di Sebastiano Serlio Bolognese*. Venice: Francesco de Franceschi Senese.

Valdambrini, Noemi. 2018. M-Bim nuovi approcci per la gestione delle collezioni d'arte. Master's thesis, Università degli Studi di Firenze.

Vignola, Jacopo Barozzi da. 1562. *Regola delli cinque ordini d'architettura*. Roma.

Vitruvius. 1829. *Dell'architettura di Marco Vitruvio Pollione libri dieci*. Milano: Giacomo Pirola.

Vittone, Bernardo Antonio. 1760. *Istruzioni elementari per indirizzo de'giovani allo studio dell'architettura civile*. Lugano: Agnelli.

Xu, Jiawei. 2021. Brick facades in Turin, 1600–1800. Master's thesis, Politecnico di Torino.

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