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The Grand Staircase of the Birago di Borgaro Palace: From Digital Model to physical scale model for the communication of construction aspects

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Abstract

The combined use of digital and physical models promotes inclusive communication and represents an important medium for presenting heritage to the community, particularly to the tourism sector.

The work presented here concerns the Grand Staircase of the Birago di Borgaro Palace in Turin, designed by Filippo Juvarra and built from 1716 onwards. The monumental staircase is located near the main atrium; its development takes place on three right-handed ramps leading to the main floor hall.

The contribution focuses on the application of digital technologies for three-dimensional modelling and digital fabrication, aimed at studying and communicating the constructive aspects of architectural heritage.

The adopted methodology involves the use of data from previous acquisitions and restitutions (TLS survey by Prof. M.C. López González, two-dimensional drawing by Arch. F. Natta) for the digital modelling of the Grand Staircase in order to retrace the formal ideation process related to the applied construction techniques.

Starting from the virtual model, through digital fabrication techniques, a physical model is created on a 1:50 scale, composed of four main blocks obtained using three vertical section planes.

The model, in addition to restoring the compositional apparatus of the decorations, aims to make understandable, explicit and readable the construction system used in the design: on the one hand, it restores the overall three-dimensional morphology of the artefact, and on the other, it offers the possibility to be explored revealing the structural composition through the constituent elements such as the ramping barrel vaults, the cross vaults that support the landings and the stiffening arches.

The physical model of the Grand Staircase of the Birago di Borgaro Palace is an example of how the physical representation of the built space can become an expression of layered and sedimented information, lending itself to the communication of knowledge even to a non-expert audience.

Keywords: *3D modelling, digital representation, scale model, digital fabrication, 3D printing.*

1. Introduction

The architectural heritage represents the cultural expression of an era, and each building, with its structure, decorative details, and constructive peculiarities, narrates a unique story inextricably linked to the historical context in which it was conceived and realised. However, the comprehension of these architectures is not always immediate, especially regarding the technical and constructive aspects that often elude the untrained eye. In this scenario, the combined use of digital and physical models can be a valuable tool for promoting inclusive communication and representing an important medium for presenting architectural heritage to the community, particularly the tourism sector. Through these tools, the constructive elements and challenges faced by architects of the past are brought to light, allowing a broader audience to appreciate the ingenuity of the masters who designed these artefacts.

The contribution focuses on the case study of the Grand Staircase of the Birago di Borgaro Palace in Turin, an architectural masterpiece designed by Filippo Juvarra and constructed starting from 1716. The Grand Staircase is located near the main atrium of the palace and develops through three right-handed ramps leading to the main floor hall (*piano nobile*). The artefact has been assumed to be a paradigmatic case study within the Turin architectural panorama, where a relatively small number of 17th and 18th-century palaces feature a staircase configured as an access structure to the only first floor without continuing to the upper floors.

In the context of Baroque architecture, the Grand Staircase takes a role of great importance, representing a crucial element within the ceremonial of entrance and welcome. It is not a simple vertical connection but rather a primary design nucleus developed with great compositional effort and scenic unity (López González et al., 2022).

The realisation of a detailed digital model of this element has allowed the exploration of its constructive aspects, highlighting not only its remarkable decorative apparatus but especially the system of vaults used in its design (Guillerme, 1987), supporting the three ramps of stairs and landings. Thanks to surveying, drawing, and three-dimensional digital modelling techniques, it has been possible to virtually reconstruct the architectural elements with high accuracy, analysing the employed constructive solutions.

In order to make this geometric and constructive information accessible, a scale model has been created, translating the data elaborated in the digital modelling environment into physical form (Colabella, 2017). The model, obtained through digital fabrication techniques, allows users to appreciate and understand the constructive system of the Grand Staircase, thanks to its division through the introduction of three vertical section planes.

The development of this workflow, from the digital model to the physical scale model, gives rise to an effective communication medium, allowing the explication of an aspect not immediately perceptible in the Grand Staircase of the Birago di Borgaro Palace.

2. Previous related works

Among the research and studies dedicated to the Birago di Borgaro Palace, it is necessary to mention the monographic work curated by Elena Gianasso, Albina Malerba, and Gustavo Mola di Nomaglio (2019), as well as the work of Paolo Cornaglia (2000). Regarding the role of the Grand Staircase in Juvarra's architecture, it is significant to mention the essay by Roberto Caterino (2018) and, finally, on the application of geometric-proportional and constructive criteria in the design of Staircases, the article by Cornelie Leopold (2019) and the book by Vincenzo Cirillo (2019).

Regarding the treatise sources, previous studies (López González et al., 2022) have focused on the works of Andrea Palladio (1570), Guarino Guarini (1737) and Bernardo Vittone (1760, 1766), while concerning manuals, the studies have involved the books of Giovanni Curioni (1870) and Gustav Breymann (1884).

The metric survey conducted by Prof. M.C. López González followed interdisciplinary research experiences between representation and constructive history on stereotomic staircases in Spain (López González and Marín Sánchez, 2020; Almagro and Gorbea, 2019; Puche Fontanilles et al., 2017). This approach has allowed for an in-depth study of the geometric, constructive, and structural aspects of monumental Staircases, integrating historical, architectural, and technical knowledge. The previously conducted metric survey represented an indispensable tool for understanding, preserving, and communicating this architectural heritage of high value.

3. Aims and objectives of the research

The present contribution explores the potential of digital technologies in three-dimensional modelling and digital fabrication, applying them to the study and communication of the constructive aspects of architectural heritage, with particular reference to the tourism sector. Through the selected case study of the Grand Staircase of the Birago di Borgaro Palace in Turin, this work aims to investigate how the integration of advanced digital tools can represent a valuable ally in the preservation, enhancement, and dissemination of architectural heritage (Spallone et al., 2021).

One of the main objectives was to create a detailed digital model of the Grand Staircase, leveraging the capabilities offered by NURBS (Non-Uniform Rational B-Spline) modelling in the RHINOCEROS 7 workspace. Through this approach, the goal was to obtain an accurate virtual representation of the work, capable of capturing the complex geometries and constructive solutions adopted by the architect Filippo Juvarra in the realisation of this extraordinary artefact.

Furthermore, the digital model represented a nodal point for the exploration and analysis of the technical and structural aspects of the work. Thanks to the functionalities offered by three-dimensional modelling software, it was possible to examine in detail the constituent elements of the Grand Staircase, such as the ramping barrel vaults, the cross vaults of the landings, and the reinforcing arches, in order to fully understand the adopted construction system (Maiezza, 2019).

An additional objective pursued in this work was to translate the digital model into a tangible physical representation, leveraging digital fabrication technologies (Scopigno et al., 2017). Through the use of FDM (Fused Deposition Modelling) 3D printing, a scale model of the work was created, capable of concretely and immediately restoring the constructive and structural aspects previously analysed in the virtual environment.

This step required particular precautions, as the physical model had to be able not only to reproduce the morphology and aesthetics of the artefact but also to clearly and effectively communicate the adopted technical solutions, making them understandable and readable for a heterogeneous audience, especially for non-experts in the field. In this context, one of the fundamental objectives was to fully exploit the potential offered by FDM 3D printing in reproducing complex geometries and architectural details to obtain a high-quality and precise physical model.

The hybridisation of digital and physical tools represents an effective approach to the communication of architectural heritage, and the contribution aims to enrich the scientific research on the role of digital technologies in the conservation and communication of cultural heritage (Neumüller, 2014). By sharing the results obtained and the methodologies adopted, the intent is to stimulate further reflections and research in this field, fostering a fruitful exchange of knowledge.

4. Methodological workflow structure

The adopted methodology (Figure 1) involves the use of data from previous acquisitions and restitutions (TLS survey by Prof. M.C. López González, two-dimensional drawing by Arch. F. Natta) for the digital modelling of the Grand Staircase, in order to retrace the formal ideation process related to the applied construction techniques.

Starting from the virtual model, through digital fabrication techniques, a physical model was created on a 1:50 scale, composed of four main blocks obtained using three vertical section planes (Figure 2).

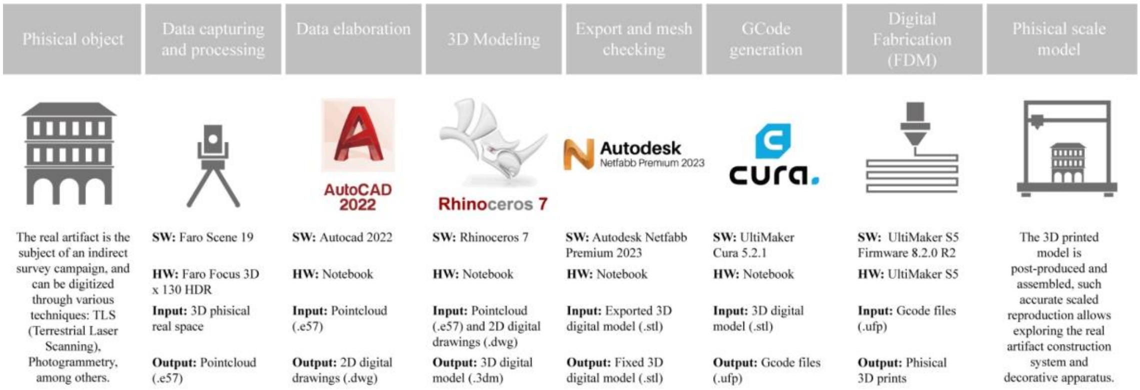


Figure 1. Summary table of the process illustrating the main steps of the adopted workflow, for the different phases is specified: the utilised Software (SW), the involved Hardware (HW), the input and the output data. Source: Pupi (2024)

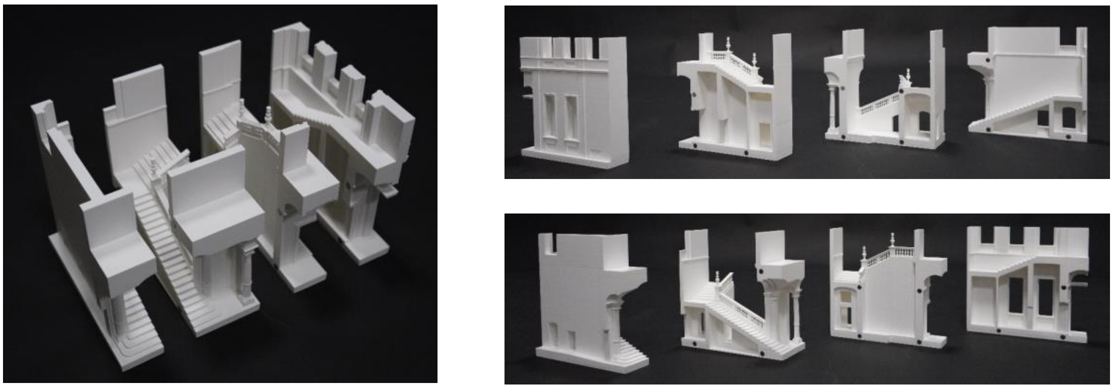


Figure 2. Photograph of the model after completion of all workflow steps. Photos were taken at the MOD Lab Arch of the Politecnico di Torino – Department of Architecture and Design. Source: Pupi (2024)

4.1. Data alignment in the digital workspace

At first, it was necessary to align the data relating to the atrium and staircase of the Birago di Borgaro Palace within the RHINOCEROS workspace, through which perform the three-dimensional modelling operations:

- The point cloud, previously captured using TLS (Terrestrial Laser Scanning) methodology, was carried out with a Faro Focus 3D x 130 HDR by Prof. M.C. López González (Figure 3). The space was scanned with a high-density resolution (one point every 7.7 and 6.11 mm at a distance of 10 meters) using the scanner's integrated camera (70 megapixels with automatic brightness adaptation). The good overall level of overlapping (21.4%) and the accuracy of the laser scanner led to a satisfactory result: the maximum error in the position of a single point in all scans was 6.7 mm, and the average error was 3.4 mm, values compatible with 1:50 scale graphic restitution. Alignment and registration were performed using Faro Scene version 19 software. It was possible to export the point cloud in *.e57* format to import the data into the RHINOCEROS workspace.
- The vector drawings of plans and sections created by Arch. F. Natta were based on the information derived from the point cloud (Figure 4). Direct survey operations complemented the drawings to complete the knowledge data: a plan was drawn up at the elevation of the underfloor rooms, which was particularly useful for the analysis of the structural and construction system: it consists of a "trumpet" staircase system, with double support of inclined barrel vaults on which the steps are positioned, while very low cross vaults form the intrados of the landings. Between ramps and landings are transverse arches, partly plugged, that stiffen the load-bearing system. The vector drawings, created using AUTODESK AUTOCAD 2022, were imported into the RHINOCEROS workspace in their native *.dwg* format. In this

way, to correctly carry out the three-dimensional modelling, it was particularly useful to subsequently be able to use the profiles of the mouldings and decorative apparatus contained within the drawings.

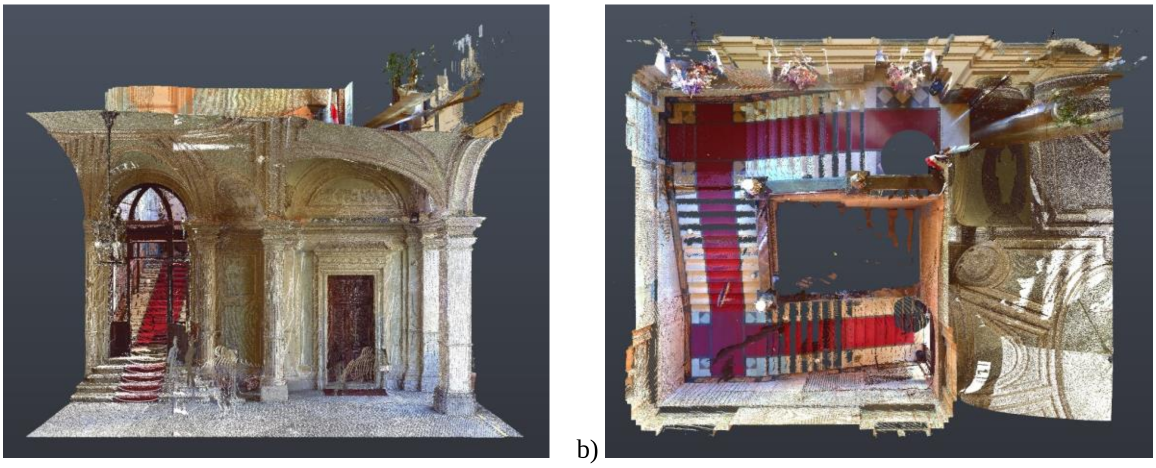

a) b)

Figure 3. Processed and trimmed point cloud: a) Atrium perspective; b) Zenithal perspective. Source: López González (2022)

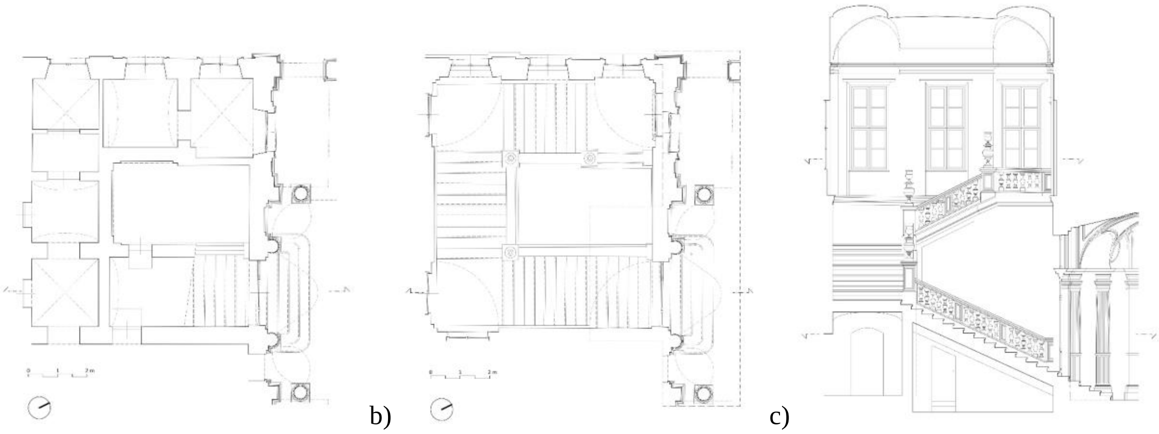

a) b) c)

Figure 4. CAD drawings: a) Ground-floor plan; b) First-floor plan; c) Section. Source: Natta (2022)

4.2. Preliminary identification of the boundaries of three-dimensional modelling

After general considerations about the desired result, the physical limits for three-dimensional modelling were identified. Although the main focus was centred on the three ramps of the Grand Staircase, it was deemed appropriate to slightly expand the identified area to confer readability to the artefact and its contingencies. The digital model included part of the atrium that allows access to the Grand Staircase and part of the rooms on the first floor that are accessible through the Grand Staircase. To use the physical model and with particular reference to its aim, extending the modelling to the vaulted covering system that completes the space hosting the Grand Staircase was not deemed necessary.

4.3. Representation scale, digital fabrication tools and level of detail

From a technical point of view, it was necessary to make complementary evaluations to influence multiple aspects of the physical model: the choice of representation scale, digital fabrication tools and material type, and the level of detail of the three-dimensional modelling. Specifically, the use of a 1:50 scale was deemed appropriate (also a coherent solution with the representation scale of the used two-dimensional drawings) in order to obtain a physical model that, on the one hand, would not require an excessive time for the fabrication process, and on the other would be able to provide a satisfactory level of detail. Although involving a partial formal simplification of the artefact, this choice also represented a compromise solution concerning the adopted digital fabrication tools.

Considering the model's geometry, the Cartesian FDM 3D printer Ultimaker 5S available at the MOD Lab Arch of the Politecnico di Torino – Department of Architecture and Design was chosen, capable of combining high detail precision with acceptable execution timing.

4.4. Draft early modelling

At this point, it was possible to complete an initial three-dimensional modelling phase in the RHINOCEROS workspace to restore the object of study through a schematic model capable of positioning the raw elements in space to be refined in a more time-consuming phase. For this purpose, the data previously aligned in the digital workspace was used: point cloud and two-dimensional drawings. Given the high complexity of the model, it was preferable first to create an undetailed digital model, which, while on the one hand was able to correctly arrange the dimensions of the constructive elements in space, on the other hand, functioned as a solid starting base through which conduct the subsequent phases of geometry refinement. From this perspective, NURBS (Non-Uniform Rational B-Splines) geometry was used, which was considered optimal in modifiability and adaptability.

4.5. Decorative apparatus complete modelling

The subsequent integrative modelling process was based on the profile curves derived from the two-dimensional drawings, making some partial simplifications where the geometry of the artefact was deemed excessively complex to the representation scale adopted for the physical model. It was considered essential to perform the digital modelling with a level of detail compatible with the limitations imposed by the adopted digital fabrication tools – such as the minimum layer height and minimum printable thickness – being aware that high 3D print resolutions inevitably entail a substantial increase in the time required for digital fabrication. In these terms, the choice of RHINOCEROS software was confirmed as an excellent solution, as this software is particularly suitable for constantly checking for parts that may be too thin to be printed (Figure 5). During this highly detailed modelling process, paying particular attention to periodically performing union operations of the so-called polysurfaces was necessary. Since this modelling was intended to function as a digital copy of a physical model made by 3D printing, it is essential to perform “clean” three-dimensional modelling, which is not afflicted by compenetrations of elements but consists of a single shell that can be recognised as representing the boundaries in the subsequent digital fabrication phase. Although, as illustrated in section 3.9, checking the meshes before the 3D printing process is still necessary, this operation can be facilitated in advance during the three-dimensional modelling stage.

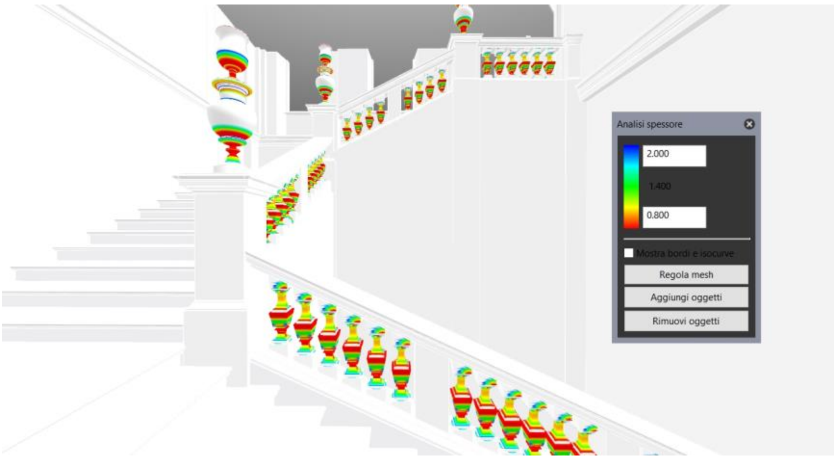


Figure 5. Perspective of thin shells thickness analysis in RHINOCEROS workspace. Source: Pupi (2024)

4.6. Digital model sectioning

In order to effectively communicate the constructive features of the Grand Staircase, it was chosen to explicate its constructive elements by breaking down the digital model into sub-shells using three vertical section planes (Figure 6). The first and third section planes intersect the first and third ramps of stairs on the axis, and consequently, the ramping barrel vaults with parallel generatrices to the perimeter walls; in this way, it is also possible to section the composite vaults (cross vaults) supporting the three landings along their axes of symmetry, thus intersecting the keystones. The second identified section plane was introduced to make the ramping barrel vault supporting the second ramp of stairs easily readable; in this case, the space is sectioned according to its transverse direction. The development of this section plane also had to provide for a shift in its position so as not to intersect the column present in the atrium. During this process, a further operation of cap the so-called poly-surfaces became necessary, obtaining solid and closed elements that constitute the macro-elements of the model. The described procedure, therefore, gives rise to a model consisting of four main blocks, which, on the one hand, restore the three-dimensional morphology of the Grand Staircase in its entirety, but at the same time, allow them to be separated, revealing its constructive composition (Figure 7).

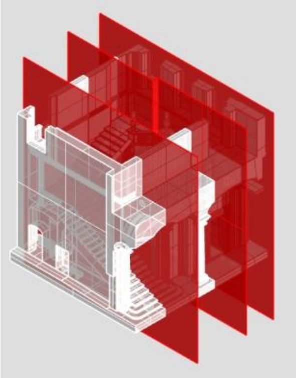
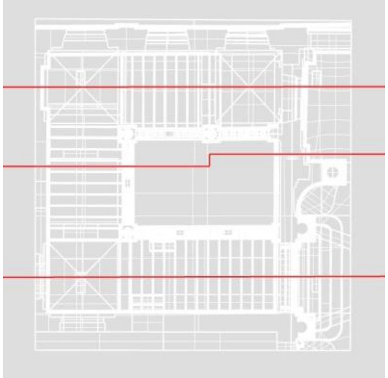
a)  b) 

Figure 6. Digital model splitting using the three section planes: a) Isometric axonometry; b) Plan. Source: Pupi (2024)

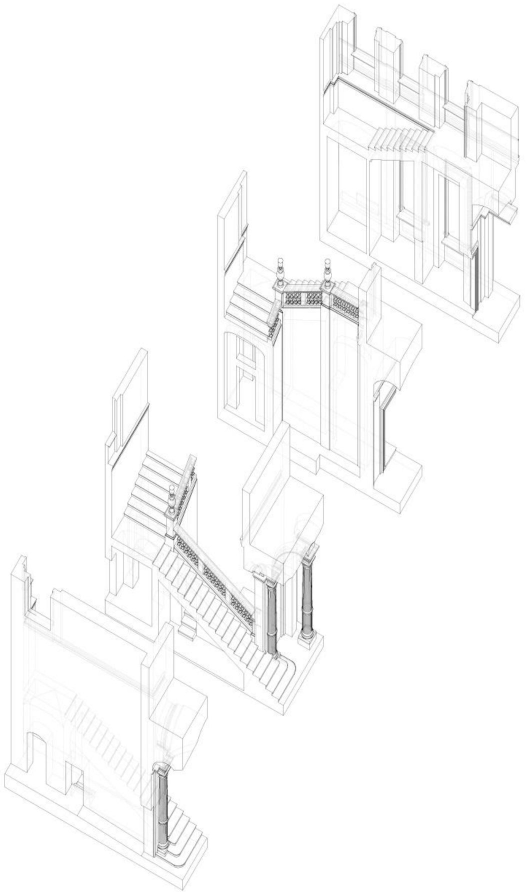


Figure 7. Overall, monometric axonometry of the four main blocks composing the model. Source: Pupi (2024)

4.7. Digital model assembly and discretisation system

As a final operation, before proceeding with the export of files destined for the digital fabrication, it was necessary to implement an assembly system in the model to make the final physical model easy to handle. From this perspective, the use of a system of cylindrical magnets with a diameter of 7 mm and a thickness of 3 mm has been considered appropriate (Figure 8):

- The chosen size and the force they apply make the assembly quite solid and allow easy disassembly.
- Since they have been embedded in the model shells, they are visually non-impactful.
- After a test on the tolerance to be used in the slot to be implemented in the digital model, they did not require glues but were assembled by a firm interlocking.

Furthermore, to optimise the 3D printing procedure, particularly delicate elements that would constitute a fragility in the printing process were identified (Figure 9). These elements, belonging to the inner shells, were isolated, constituting additional shells, printed separately, and assembled in post-production.

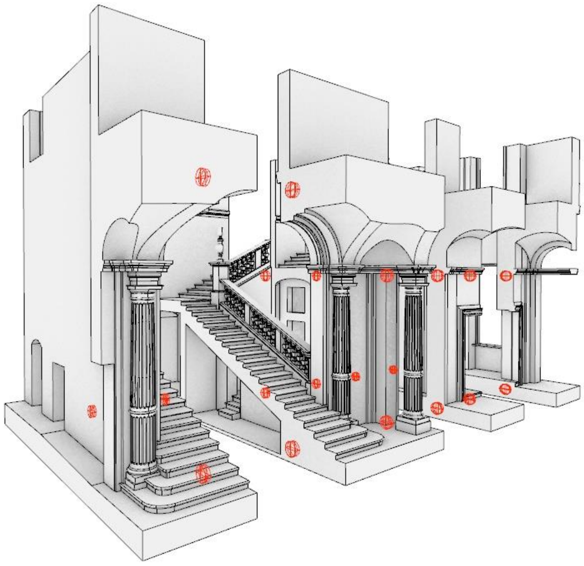


Figure 8. Filtered perspective with magnet junctions highlighted in red. Source: Pupi (2024)

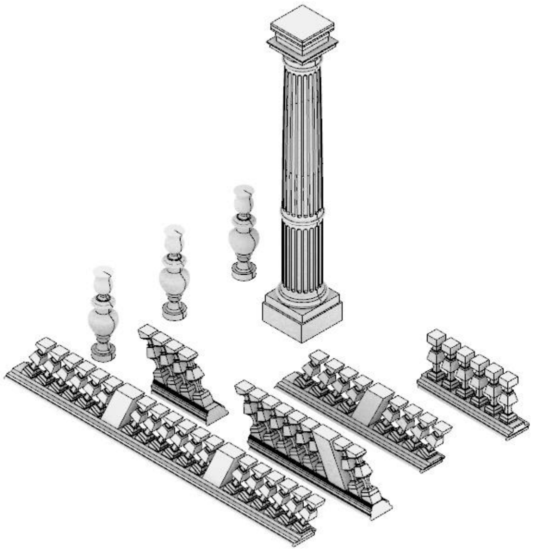


Figure 9. Isometric axonometry of isolated and distinctly printed elements. Source: Pupi (2024)

4.8. Digital model export, digital fabrication, and postproduction

Before definitively exporting the files, the geometries were transformed from NURBS to Meshes, assigning adequate tolerance parameters during the transformation process to preserve the curvatures of the vaults and other elements with curvilinear profiles (the maximum deviation detected was 0.1 mm). This operation allows for visualising the result of the geometrical transformation; in this sense, it is possible to refine the tolerance parameters to obtain a good balance between the perception of curved elements and the number of polygons in the model. Finally, it was possible to export the shells using the.*stl* format, classifying them accurately. Given the high complexity of the model, a preventive check of the Meshes was carried out to avoid possible errors in the 3D printing process. For this operation, the AUTODESK NETFABB PREMIUM 2023 software was used, which effectively tracked some issues with polygon stitching, which were easily repaired using the Extended Repair function. The fixed files were then imported into the ULTIMAKER CURA 5.2.1 slicing software, representing the last elaboration before the digital fabrication process. After a series of evaluations, it was decided to maintain the vertical orientation of the elements, except for the parapets, which were printed and rotated 180° in the xy plane. Although it was necessary to use supports extensively in the main shells, this choice was strongly influenced by the possibility of restoring with greater precision and accuracy the characters of the decorative apparatus of the Grand Staircase, avoiding sacrificing some details and making the result more aesthetically pleasing. Within the slicer, all the parameters aimed at controlling the printing process were set, for which white PLA material was entirely used, and the main ones are reported below:

- Layer height in the main shells is 0.2 mm.
- Layer height in secondary shells is 0.1 mm.
- Extrusion width is 0.35 mm.
- General print speed is 70 mm/s (with appropriate slowdowns for the shell's perimeters and first layer).
- Infill density is 8% (100% for secondary shells).
- Extrusion temperature is 210°C.
- Maximum support overhang angle is 60°.
- Support density is 15%.

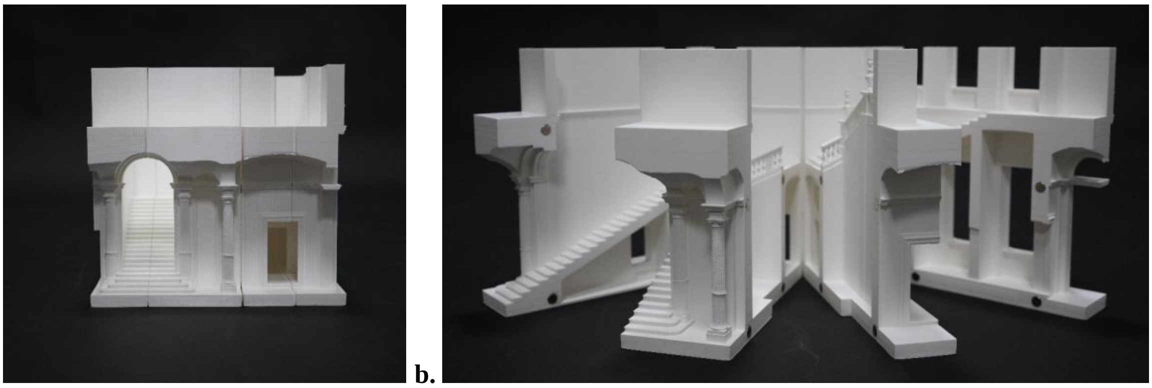
The printing process required about six days, using about 1500 g of white PLA. At the end of the digital fabrication process, during the post-production phase, the physical model got a manual process of support removal, which was removed without great difficulty, thanks to the fact that a parameter for not welding the supports to the main shell was set in the slicer (z-upper support distance of two-layer, z-bottom support distance of one-layer). This operation was followed by assembling the magnets directly fitted into the cavities provided during modelling. Lastly, the secondary shells printed separately were integrated into the physical model using cyanoacrylate glue.

5. Achieved results

The communication of the spatial system of the Grand Staircase can take advantage of the continuum between virtual and physical: starting from an accurate NURBS digital modelling carried out in RHINOCEROS, the adopted workflow allowed translating into physical form the information related to the constructive and structural aspects of this architectural masterpiece, offering a dynamic experience for the public who can explore the physical model both in its entirety (Figure 10a) and in its separate sections (Figure 10b).

One of the main objectives of this research was to make the construction system used in the design of the Grand Staircase understandable, explicit and readable. In this sense, the physical model proved to be a highly performant tool, capable of restoring not only the overall three-dimensional morphology of the work but also able to offer the possibility of exploring its structural composition through its constituent elements.

Thanks to the choice of realising the physical model through FDM 3D printing, it was possible to reproduce the Grand Staircase with good fidelity and a good level of accuracy concerning the level of detail assumed during digital modelling, allowing users to appreciate its complex geometry.



a. b.

Figure 10. a. Whole physical model; **b.** Separate sections of the physical model. Source: Pupi (2024)

A particularly relevant aspect of the physical model is the possibility of appreciating the reinforcing arches, which are fundamental elements to ensure the stability and solidity of the entire structure. These elements, often hidden from view or difficult to understand in two-dimensional representations, have been made explicit and readable in the model, allowing users to note their importance and strategic arrangement within the artefact.

Moreover, the model has made it possible to almost entirely reproduce the decorative apparatus of the Staircase, restoring the ornamental elements that enrich the architectural masterpiece. Thanks to digital fabrication, it was possible to reproduce thin and refined details, such as the moulding system and the conformation of the parapet's abutments, allowing users to appreciate the work of 18th-century artisans.

A fundamental aspect of this research was to make the overall Grand Staircase constructive system accessible to a heterogeneous audience, including those who do not have specific training in the field of architecture. Thanks to the tangible and three-dimensional nature of the physical model, even inexperienced users can intuitively and engagingly explore and understand the staircase's constructive and structural aspects.

An additional value of this project lies in its potential for enhancing and disseminating cultural heritage: the physical model of the Grand Staircase of the Birago di Borgaro Palace can potentially be exhibited in museum contexts or cultural events, becoming a form of knowledge transmission capable of attracting the interest of a broad audience. Furthermore, thanks to its portable and easily replicable nature, the model can be shared and disseminated in various locations, contributing to the promotion and knowledge of this valuable architectural artefact.

6. Limitations, application potential, and conclusions

The creation of a scale physical model of the Grand Staircase of the Birago di Borgaro Palace, obtained through FDM 3D printing from a NURBS digital model created in RHINOCEROS, represents a notable achievement in communicating the constructive aspects of this artefact. The contribution analyses how the physical representation of the built space can become an expression of layered and sedimented information, lending itself to the communication of knowledge even to a non-expert audience.

However, it is important to recognise the limits and potentials of this approach in order to further improve its effectiveness in the communication of architectural heritage.

One of the main limitations of using FDM 3D printing to realise the physical model lies in the resolution and precision of the reproduced geometries. Although this additive 3D printing technique offers valuable advantages in terms of flexibility and contained costs, the quality of the printed surfaces and the restitution of architectural details may be inferior to other digital fabrication techniques, such as stereolithography.

FDM 3D printing imposes some limitations on the choice of materials, which can affect some aspects of representation, such as the surface finishes of the original work. This aspect could limit the ability of the physical model to fully communicate the material characteristics and construction choices. From this perspective, an alternative may be represented by subtractive digital manufacturing processes, such as CNC milling (Ronco, 2021).

Despite these limitations, the potential offered by this approach is remarkable and deserves to be further explored. The possibility of translating a highly detailed digital model into a tangible physical representation lends itself to a multidirectional experience through its observation. Furthermore, from a perspective of accessibility and inclusiveness, the realisation of the model could include particular precautions – particularly regarding the more thin and fragile elements – to allow a tactile experience (Spallone et al., 2023).

A further potential of this approach is the possibility of creating physical models at different scales, allowing the exploration of the work from different perspectives and adapting to the potential needs of different exhibition or educational contexts. In the proposed methodology, the representation scale of 1:50 was chosen as a compromise solution between the overall size of the physical model, the level of detail that can be afforded by high-resolution FDM 3D printing technology, and digital fabrication time. This choice, albeit to a minimal extent, involved some simplifications regarding the profiles of some mouldings and some adaptations due to the need to conform slender or thin elements to the requirements of digital fabrication. From this perspective, the fabrication of a physical model on a different scale, such as 1:20 or 1:10, could allow a more in-depth analysis, especially regarding the decorative apparatus of the Grand Staircase.

The combination of the NURBS digital model and the physical model production allows for further layering and sedimentation of information within a single representation. The integration of innovative XR (eXtended Reality) digital technologies could further enrich the users' experience, overlaying additional information onto the physical model or allowing for virtual exploration of the digital model (Spallone et al., 2021):

- The application of AR (Augmented Reality) could use the physical model as a three-dimensional marker and overlay both additional technical information, such as details regarding the employed construction techniques, and additional social information, such as the uses and customs of the era related to the ceremonial of entrance in which the Grand Staircase played a prominent role.
- The application of VR (Virtual Reality) could instead be used for remote fruition of architectural heritage. The digital model could be further elaborated through texture mapping techniques aimed at rendering not only the geometry and morphology of the Grand Staircase but also its highly characterised real perception through frescoes and fine materials. Moreover, complementary annotations and information could also be overlaid during the immersive experience in a completely virtual environment.

In conclusion, through a representative case study, the contribution analyses how combining digital and physical models can become a powerful tool for communicating complex information to a highly heterogeneous audience. The work carried out intends to stimulate research and experimentation perspectives in the field of communication of architectural heritage, and it is essential to continue exploring and refining the techniques used and the consequent methodology employed in order to fully exploit the potential offered by the integration of different types of digital and physical representation.

7. Acknowledgements

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8. References

Almagro Gorbea, A. (2019). Half a century documenting the architectural heritage with photogrammetry. *EGE Revista de expresión gráfica en la edificación,* 11, 4–30.

Breymann, G.A. (1884). *Trattato generale di costruzioni civili, con cenni speciali intorno alle costruzioni grandiose*. Paravicini, Vallardi.

Caterino, R. (2018). «Non sono le scale piccolo ornamento d'un gran palazzo». Scaloni e cerimoniale nei progetti di Filippo Juvarra". In G. Dardanello (Ed.), *Cultura, arte e società al tempo di Juvarra* (pp. 91–126). Olschki Editore.

Cirillo, V. (2019). *Riflessioni e suggestioni tra geometria e forma. Le scale del '700 napoletano*. La scuola di Pitagora editrice.

Colabella, S. & Pone, S. (2017). *MAKER. La Fabbricazione Digitale per l'architettura e Il Design*. Progedit.

Cornaglia, P. (2000). Il Palazzo Birago di Borgaro. In P.L. Bassignana (Ed.), *Le strade e i palazzi di Torino raccontano* (pp. 171–208). Centro Congressi Torino Incontra.

Curioni, G. (1870). *Costruzioni Civili, Stradali ed idrauliche*. Augusto Federico Negro.

Gianasso, E., Malerba, A. & Mola di Nomaglio, G. (2019). *Palazzo Birago di Borgaro*. Centro Studi Piemontesi.

Guarini, G. (1737). *Architettura civile*. Mairesse.

Guillerme, J. (1987). Il modello nella regola del discorso scientifico, "Rassegna", *Maquette, 9*(32), 29–37. C.I.P.I.A.

Leopold, C. (2019). Geometric Aspects of Scalalogy. *Journal for Geometry and Graphics, 23*(2), 221–233.

López González, M.C. & Marín Sánchez, R. (2020). Ashlar Staircases with Warped Vaults in Sixteenth to Eighteenth Century Spain. *Nexus Network Journal*, *22*(4), 959–981.

López González, M.C., Spallone, R., Vitali, M., Natta, F. & Pupi, E. (2022). Lo scalone d'onore nell'architettura civile in età barocca a Torino. Il caso di palazzo Birago di Borgaro. In V. Burgassi, F. Novelli, & A. Spila (Eds.), *Scale e risalite nella Storia della Costruzione in età Moderna e Contemporanea* (pp. 265–284). Politecnico di Torino.

Maiezza, P. (2019). *Ricostruendo in digitale*. Publica.

Neumüller, M., Reichinger, A., Rist, F. & Kern, C. (2014). 3D Printing for Cultural Heritage: Preservation, Accessibility, Research and Education. In M. Ioannides & E. Quak (Eds.), *3D Research Challenges in Cultural Heritage: A Roadmap in Digital Heritage Preservation* (pp. 119–134). Springer. https://doi.org/10.1007/978-3-662-44630-0_9

Palladio, A. (1570). *I quattro libri dell'architettura*. De Franceschi.

Puche Fontanilles, J.M., Macias Solé, J.M., Toldrà Domingo J.M., & de Solà-Morales, P. (2017). Más allá de la métrica. Las nubes de puntos como expresión gráfica semántica. *EGA. Revista de expresión gráfica arquitectónica, 22*(31), 228–237.

Ronco, F. (2021). Prototypes to Increase Museum Experience and Accessibility. Palazzo Mazzonis' Atrium in Turin: The Work in Progress. In M. Ioannides, E. Fink, L. Cantoni, & E. Champion (Eds.), *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection* (pp. 605–613). Springer International Publishing. https://doi.org/10.1007/978-3-030-73043-7_52

Scopigno, R., Cignoni, P., Pietroni, N., Callieri, M. & Dellepiane, M. (2017). Digital Fabrication Techniques for Cultural Heritage: A Survey. *Computer Graphics Forum, 36*(1), 6–21. https://doi.org/10.1111/cgf.12781

Spallone, R., Lamberti, F., Trivel, G.M., Ronco, F. & Tamantini, S. (2021). AR e VR per la comunicazione e fruizione del patrimonio al Museo d'Arte Orientale di Torino. In A. Arena, M. Arena, D. Mediati, & P. Raffa (Eds.), *Connettere. Un Disegno per Annodare E Tessere. Linguaggi Distanze Tecnologie, Atti del 42° Convegno Internazionale dei Docenti delle Discipline della Rappresentazione, Reggio Calabria, Messina* (pp. 2659–2676). FrancoAngeli. https://doi.org/10.3280/oa-693.150

Spallone, R., López González, M. C., Vitali, M., Bertola, G., Natta, F. & Ronco, F. (2021). From survey to 3D modelling to digital fabrication. A workflow aimed at documenting and transmitting built heritage. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIII-B2-2021*, 619–626. https://doi.org/10.5194/isprs-archives-XLIII-B2-2021-619-2021

Spallone, R., Vitali, M., Quadrio, D., Vigo, L., Landi, M., Ronco, F., Bertola, G., Natta, F. & Pupi, E. (2023). Digitisation, 3D modelling and digital fabrication: an accessibility project for MAO in Turin. In A. Sdegno, & V. Riavis (Eds.), *DAI – Il Disegno per l'Accessibilità e l'Inclusione* (pp. 596–615). Publica.

Vittone, B.A. (1760). *Istruzioni elementari per indirizzo de' giovani allo studio dell'Architettura Civile*. Agnelli Stampatori.

Vittone, B.A. (1766). *Istruzioni diverse concernenti l'officio dell'Architettura Civile*. Agnelli Stampatori.

