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# The Circular Helical Staircase at Palazzo Spada

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**Abstract**
The paper deals with the unpublished survey and geometric analysis of the circular helical staircase built around 1660 in Palazzo Spada's wing on Via del Polverone in Rome. Its role in the development of the place and the history of its design process are addressed thanks to historical drawings and the reference model proposed both in the treatise and construction between the fifteenth and seventeenth centuries. A description of the 3D digital survey procedures is followed by the reconstruction of a NURBS 3D model that describes the staircase and its geometric properties. Three helical turns of the staircase undergo an in-depth analysis of the slope angle thanks to the development of the helical lines. This leads to the recognition of the main features of this staircase: its unique central structure; the implementation of geometrical proportions descending from Andrea Palladio's treatise; the changes of the slope angle that characterize the staircase flights and the space they generate.

**Keywords** Helical staircase · Architectural survey · 3D modelling · Geometric analysis · Historical drawings · Palazzo Spada

## Introduction

The helical circular staircase inside Palazzo Spada in Rome, in the wing overlooking Via del Polverone, is an object of great interest for several reasons.

It resulted from a series of design intentions produced for Cardinal Bernardino Spada between 1650 and 1661 by multiple figures such as Francesco Borromini and Francesco Righi, Vincenzo Della Greca and Valerio Penna (Tabarrini 2008: 30–45). In fact, the Cardinal was animated by the desire to enlarge the building towards the south-west and focused his attention on this vertical connection in an attempt to link the rooms dedicated to women—which were located on the main upper floors of the

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old structure—with the outdoor spaces avoiding the use of the grand staircase. The extension of this part of the building saw the elaboration of high-impact projects for the distribution of different rooms with development towards the main garden and the reconfiguration of the piano nobile, but attention was also paid to the development of the single staircase in terms of its formal control and construction technique (Neppi 1975: 133–174; Tabarrini 2008: 79–101; Farroni 2019: 19–44; Farroni and Mancini 2020: 47–68; Farroni 2020: 1139–1160).

At present, researches are not able to univocally identify the author of this staircase, so acquiring 3D digital survey data and an in-depth examination of its relationship with the cultural tradition on the subject is essential.

The geometry management followed in the construction and structural configuration are related to the design issue, while their execution is described in the measurement books that are held in the Capitoline Archives. The analysis of the possible design references supports the survey data management, and this essay intends to set out some considerations on this aspect.

It is worth noting that several vertical connections were modified and inserted into the palace in the 30 years of the Spada patronage. In the current Galleria Spada, there is another helical oval-shaped staircase attributed to Francesco Borromini, dating back to the years between 1653 and 1657, which replaced an original sixteenth-century U-shaped structure. Two staircase bodies are thus configured in the extension of the old sixteenth-century layout together with two new volumes with a longitudinal development towards Via Giulia. Other vertical elements with a smaller circular plan are placed in the palace corners and connect the mezzanines to the main floors (Fig. 1).

The uniqueness of the structural solution adopted, which sees a change in the type of central support and the surfaces covering the helicoidal ramp, makes it unique in seventeenth-century Roman architecture.

Moreover, it should be emphasised that this present survey is unpublished. In fact, there were no accurately acquired digital data, nor were there any surveys verifying the exact shape of the helical circular staircase and its plan, characterised by roughly trapezoidal pillars that develop from a continuous wall structure.

## Methodology

The methodology described below is adopted for the study of the circular helicoidal staircase. The staircase is characterised by a problematic attribution and a construction phase with structural failures. The survey aims to acquire data that allows for geometric, morphological, and structural considerations and the reading of the sequence of stratifications/constructions. Therefore, the aim is to begin verifying the narrative of the construction site books and the originality of the parts.

The methodology is developed in several stages. The first consists of analysing the context at different levels: a broader one concerning the theoretical-design framework and the previous reference constructions; one circumscribed to the case study concerning the historical sources directly referable to the object, both graphic and textual. The comparison and synthesis of this research direct

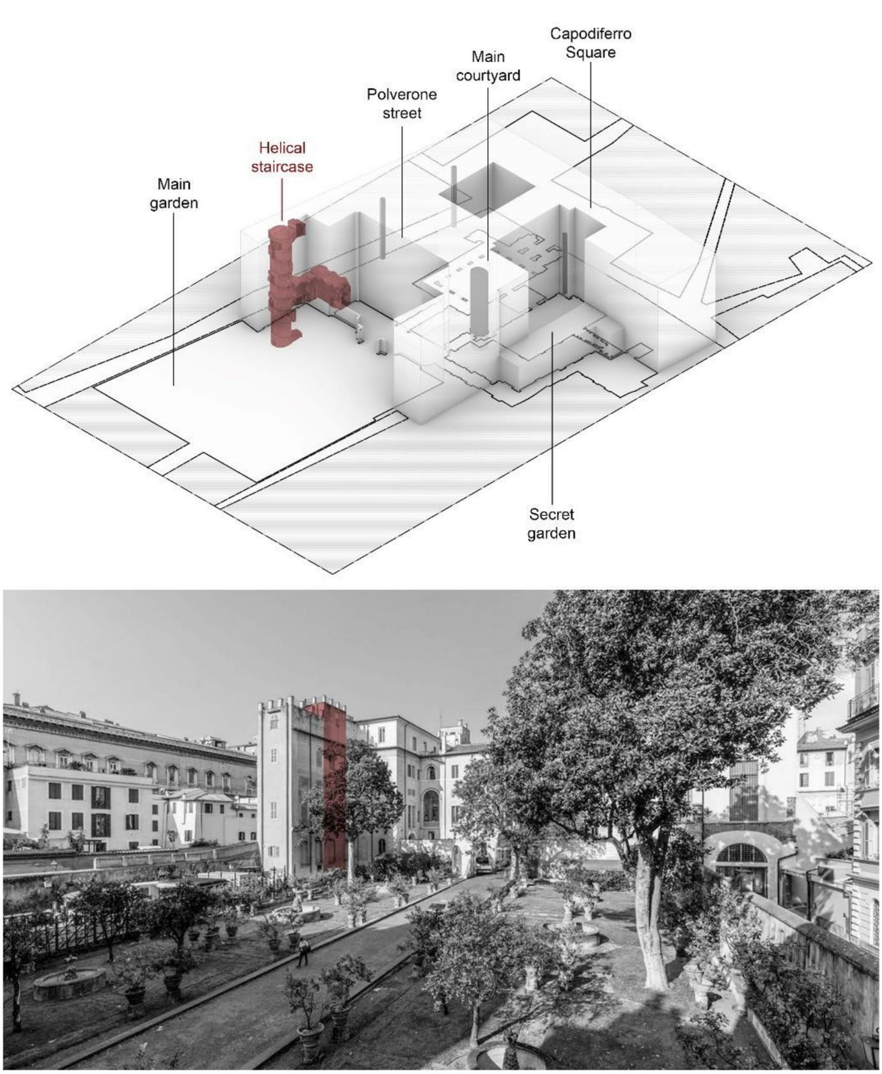


**Fig. 1** Above Palazzo Spada's volumetric model of the seventeenth-century layout, in red the helical staircase on Via del Polverone and in dark grey the other helical staircase in the palace (Image: authors); below picture of Via del Polverone wing from Via Giulia (Image: authors)

the methodology's subsequent phases, which consist of the survey and geometric analysis of the artefact through three-dimensional digital representation.

The reading of the theoretical design context reveals the specific cultural and operational references, highlighting the architectural treatises between the fifteenth and seventeenth centuries that inspired the designer and the local technical tradition, referring to the Roman and Latium territories, but also to other regions of central Italy.

Alongside this phase, historical survey and project drawings, that were made to meet the client's continuous transformation requests, were analysed and interpreted. Thus, the extrapolated reflections defined the criteria for the acquisition phases of the object under investigation.

The direct approach to the built object is therefore divided into two stages. The first is the three-dimensional digital survey, which aims at the objective acquisition of the morphology of the artefact and its constituent elements. It prepares the database for two-dimensional analytical processing, such as dimensional-metrological and proportional, and three-dimensional analysis, concerning the geometric properties of the curves and surfaces, useful to define the spatial configuration of the circular helical staircase.

Thus, the actual extent acquisition of the object and the verification of information with the broader survey—performed by the authors as part of the research on the architectural and figurative episodes of the seventeenth century at Palazzo Spada—opened scientific considerations that would not otherwise have been possible.

To date, a complex but not yet exhaustive cognitive picture of the individual work has been provided. However, it highlighted the constituent architectural elements and the possibility for a scientific data-based comparison with other realisations in synchronic and diachronic studies.

## Between Theorisation and Constructive Intent: Treatise References, Design Hypotheses and Helical Staircase Constructions

The helical staircases were adopted in ancient Greek and Roman architecture, as witnessed by multiple ancient ruins, but their use was mainly reserved for monumental buildings (Miles 1998). Their emergence as an architectural theme mainly links to medieval stereotomic experiments where the helical staircase develops its spatial potential, first experimenting with the dissolution of the outer walls and then the progressive emptying of the central well (Templer 1995: 60–72), and test different geometrical solutions (Benítez Hernández and Valiente López 2015).

The famous 'Leaning Tower' of the Cathedral and the Saint Nicola bell tower in Pisa represent Italian examples of this medieval tradition (Templer 1995: 60; Alberti et al. 2015). However, primary samples of stereotomic helical staircases can be found in the southern region of the peninsula, where the political relationship with the Spanish and French set up the opportunity for an artistic mixture. The *vis de saint-gilles* stair at Castello Maniace in Syracusae (Bares 2007) and the staircase at Castel Nuovo in Naples (Calvo López and De Nichilo 2005) are good examples of this artistic phenomenon. In any case, it was not until the late Middle Ages that the size and significance of staircases began to grow until they became a central theme in the design of Renaissance and Baroque architecture (Chastel and Guillaume 1985).

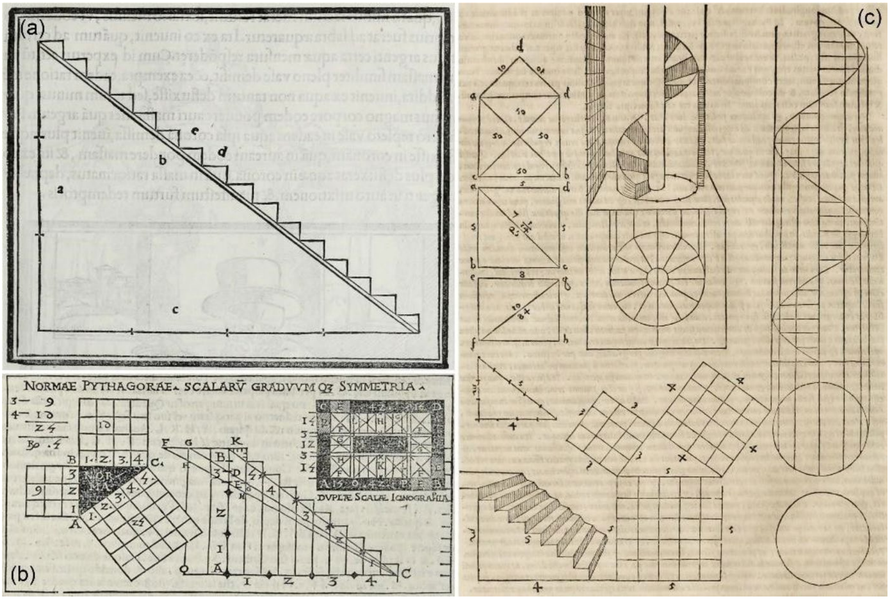


**Fig. 2** Staircase from *Liber IX* of Vitruvius' *De architectura*: **a** Giovanni Giocondo (1511: p. 85r); **b** Cesare Cesariano (1521: p. CXLV-v); **c** Daniele Barbaro (1567: p. 270)

The reference tradition of the circular helicoidal staircase of Palazzo Spada is different from the medieval stereometric one. It refers, on the one hand, to the reinterpretation of antiquity and the classics which started in the fifteenth century by Renaissance architects, on the other hand, to the experiences of military architecture of the same period and, finally, to the brick masonry construction tradition.

The architects from the fifteenth and sixteenth centuries did not have any significant ancient sources on the subject since Vitruvius only speaks of stairs in *Liber IX* of *De architectura* exclusively to define the ramps' slope through an application of Pythagoras' theorem. It is interesting to note how the figure that illustrates this passage of the treatise acquires an increasing architectural value as the editions progress (Fig. 2): from the simple diagram in the first illustrated edition by Giovanni Giocondo (Vitruvius 1511: 85r), to the planimetric scheme of a staircase with straight flights in the vernacular edition by Cesare Cesariano (Vitruvius 1521: CXLV-v), to the representations in plan, elevation and perspective of a helical staircase in the edition by Daniele Barbaro (Vitruvius 1567: 270).

Perhaps following the Vitruvian example, Leon Battista Alberti had been succinct in speaking of staircases in his treatise *Della architettura*, by only giving indications of the slope, the maximum number of steps per flight, and the inclusion of landings (Alberti 1565: 33–34).

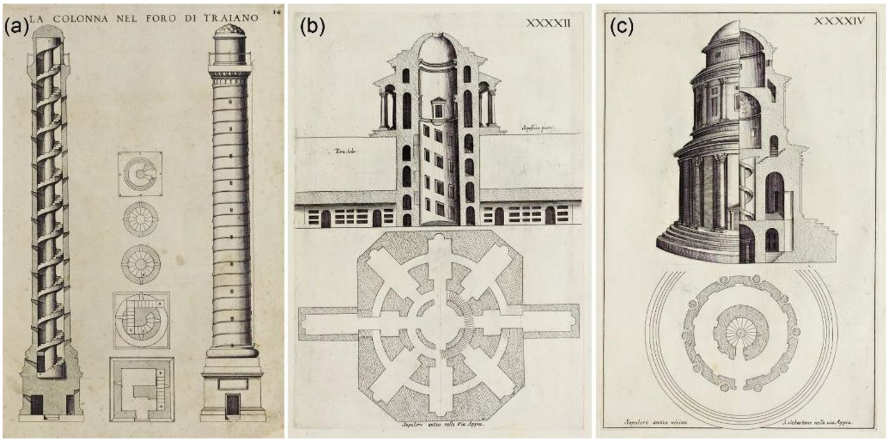


**Fig. 3** Ancient Roman helical staircase published between sixteenth and seventeenth centuries: **a** Trajan's Column (Image: Labacco 1559: p. 16); **b** and **c** tombs along the Appian Way (Image: Montano 1691: pl. XXXXII, XXXXIV)

There were undoubtedly more abundant examples provided by ancient monuments that were carefully surveyed[1] and sometimes even published in collections dedicated to ancient remains. This is the case with Trajan's Column (Labacco 1559: 16) and its internal helical staircase, or the often imaginative reconstructions of tombs along the Appian Way with their single or double helical staircases (Montano 1691: XXXXII, XXXXIV) (Fig. 3).

However, the interest in this architectural theme is well testified by the graphical studies left by great authors in their series of treatises—which gave ample space to staircases between the second half of the sixteenth century and the seventeenth century—and, finally, by numerous constructions that became established as examples.

Francesco di Giorgio Martini left a wealth of studies in the manuscript of his *Trattato di architettura*, preserved in the Biblioteca Nazionale Centrale in Florence (Fondo Nazionale, Ms. II.I.141), regarding the functional role of staircases and their positioning within civil and military buildings.

These studies show a general preference for linear ramps and the introduction of circular ramps for military buildings (Martini XV cent.). Unlike the Sienese architect, Leonardo da Vinci's studies focus on typological and formal experimentation. His sketches in *Manuscript B* of the Institut de France (Ms. 2173) show several solutions for multiple flight staircases in which the flows do not intersect (Leonardo Ms. 2173): an example of a quadruple staircase drawn in

[1] Particularly significant in this regard is the extensive graphic documentation of the Imperial Forums by architects such as: Giuliano da Sangallo, Antonio da Sangallo il Vecchio, Antonio da Sangallo il Giovane, Fra' Giocondo, Simone del Pollaiolo, Baldassarre and Sallustio Peruzzi, Andrea Palladio, and Giovanni Antonio Dosio (Viscogliosi 2000).

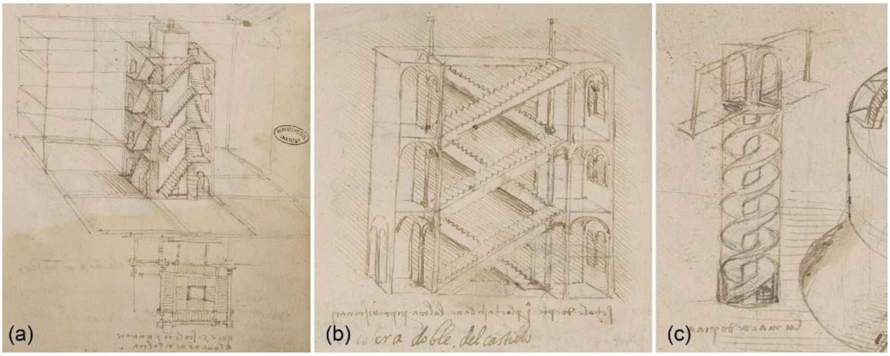


**Fig. 4** Leonardo da Vinci, Manuscript B, solutions for multiple flights stairs: **a** f. 47r; **b** f. 68v; **c** f. 69r

plan and axonometry (f. 47r), an axonometric study for a double staircase with crossed parallel flights (f. 68v) or, again, a helical double flight staircase with a 180 degree offset start (f. 69r) sketched in axonometry (Fig. 4).

Established research on stairs is confirmed by the increasing space reserved to the topic in treatises on architecture and perspective during the sixteenth and seventeenth centuries (Cirillo 2018: 177–188). The first author to deal extensively with the subject is Sebastiano Serlio. In *Il secondo libro di prospettiva* of his treatise, dedicated to perspective and scenography, he presents several examples of straight staircases on square or composed layouts, and proposes the standard measurements of one foot for the tread and half foot for the riser of the steps (Serlio 1545: 51v–57v). However, his most significant contribution to the design of helical staircases is found in *Il primo libro di geometria*, where Serlio defines four ways to design ovals (Serlio 1545: 17v–18v), a geometric matrix widely adopted between the sixteenth and seventeenth centuries.

More decisive for the typological standardisation of the staircase's architectural theme is the contribution given by Andrea Palladio in his *I quattro libri dell'architettura* where, at the end of *Libro primo*, he presents eight types of staircases organised according to two criteria: the shape of their geometrical layout—rectilinear or curvilinear—and the structural solution, with cantilevered steps or with central support. This classification is followed by the presentation of two particular typologies, with several systems of parallel ramps that do not intersect: one with a circular layout and four ramps, freely inspired by the Chambord Castle staircase, and one with crossed rectilinear ramps, inspired by ancient structures seen in Rome (Palladio 1570: 60–66).

Palladio first deals with distributive questions regarding the positioning of staircases in buildings and then defines some dimensional aspects: the ramps must be at least four feet wide (ca. 140 cm), and twice as long as the height they climb; they may contain a maximum of eleven or thirteen steps, after which a landing must be inserted; the height of the steps must be between four and six

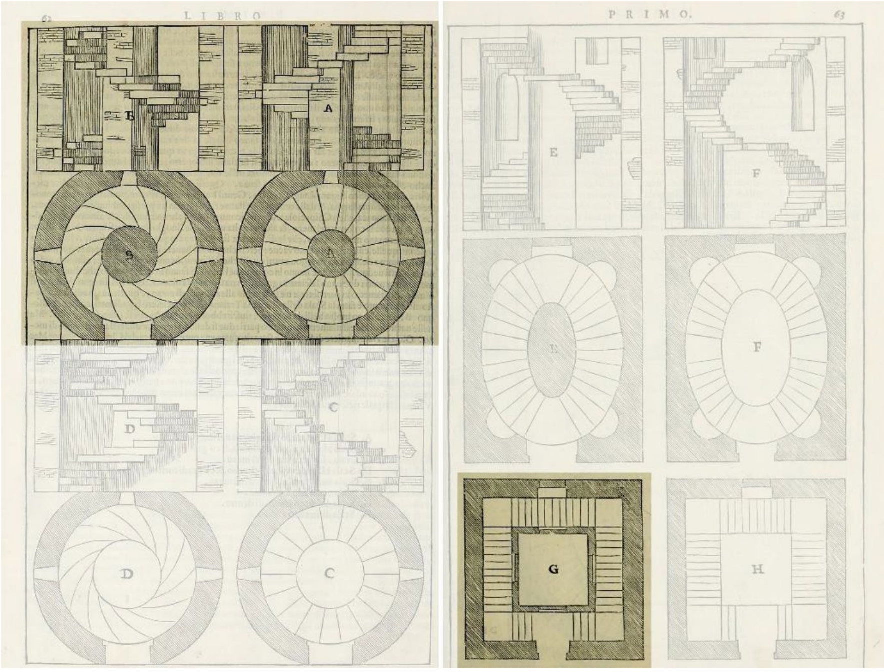


**Fig. 5** Andrea Palladio, *I quattro libri dell'architettura, Libro primo. Cap. XXVIII 'Of Staircases, and Various Manners of them'* (Image: Palladio 1570: pp. 62–63)

foot ounces (ca. between 11.5 and 17.3 cm), their depth must be between one foot and one and half foot (between ca. 34.6 and 52 cm)[2].

Among the eight main typologies listed by Palladio, the most interesting are typologies A, B, and G (Palladio 1570: 62–63), as they present significant geometric affinities with the circular staircase of Palazzo Spada. Typologies A and B present a circular 'snail staircase' with steps attached to the external wall and a solid central pillar. When designing this type of staircase, Palladio recommends the use of specific proportional ratios: for Type A, the width of the room should be divided into three parts, assigning one to the central pillar and one to the steps on either side; for Type B, the room should be divided into seven parts, assigning three to the central core and two to the steps on either side. In contrast, Type G, although showing a staircase with rectilinear flights, presents the type 'with wall inside', i.e., a continuous linear support. This latter element characterises the basement floors of the staircase in Palazzo Spada, and the particular vertical supports for the above-ground floors could derive from this by progressive subtraction (Fig. 5).

The closest model to the Palazzo Spada staircase in the treatises comes from Egnazio Danti's comments on Iacopo Barozzi da Vignola's treatise *Le due*

[2] One ounce is equivalent to 1/12 of the reference measurement unit. For this calculation, the equivalence between one Vicentine foot and 34.60 cm was adopted.

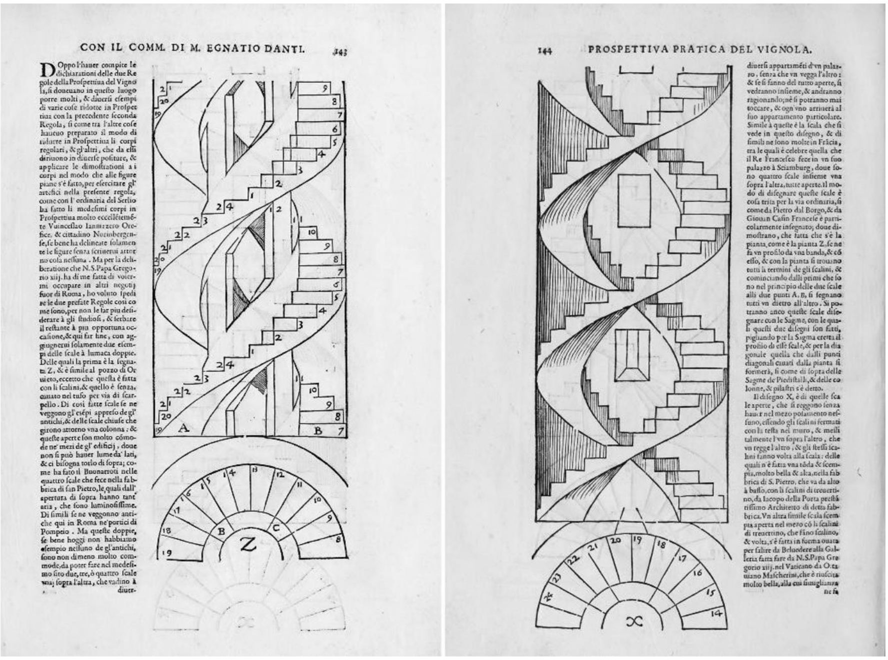


**Fig. 6** Egnazio Danti, *Le due regole della prospettiva pratica di Iacopo Barozzi da Vignola* (1583). Construction diagram of a double helical staircase with internal pillars (Image: Barozzi 1583: pp. 143–144)

*regole della prospettiva pratica*. After finishing his exposition of the two rules of perspective, Danti inserts an appendix of a few pages where he presents two types of double helicoidal staircases, i.e., composed of two independent flights with starting points shifting 180 degrees (Barozzi 1583: 143–144). The first example, identified by the letter Z, is of great interest because it features an empty central well, with steps supported by a continuous wall emptied to such an extent by the windows that it looks like a system of pillars. Danti's example does not seem to envisage the use of landings. As a result, each complete spiral requires 24 risers, twice the number prescribed by Palladio. The second example, marked X, is similar but has completely cantilevered steps (Fig. 6).

The subsequent contributions made by the treatise writers between the seventeenth and eighteenth centuries move between compilation, formal research without significant typological novelties, and the development of solutions that hybridise the previous types in schemes of ever-increasing complexity and magniloquence. For example, the contributions of Vincenzo Scamozzi (1615: 312–317), Francois Blondel (1698: 671–702) or Guarino Guarini (1737: 68–70; IV, XVII, XVIII), testify the stylistic transition towards the more mature Baroque.

The typologies found in these treatises are reflected and extended in the Baroque construction practices. In contrast, the treatises did not infrequently refer to realised works, which they often do not describe faithfully. The realised examples that show the greatest affinity with the circular helical staircase in Palazzo Spada belong to two

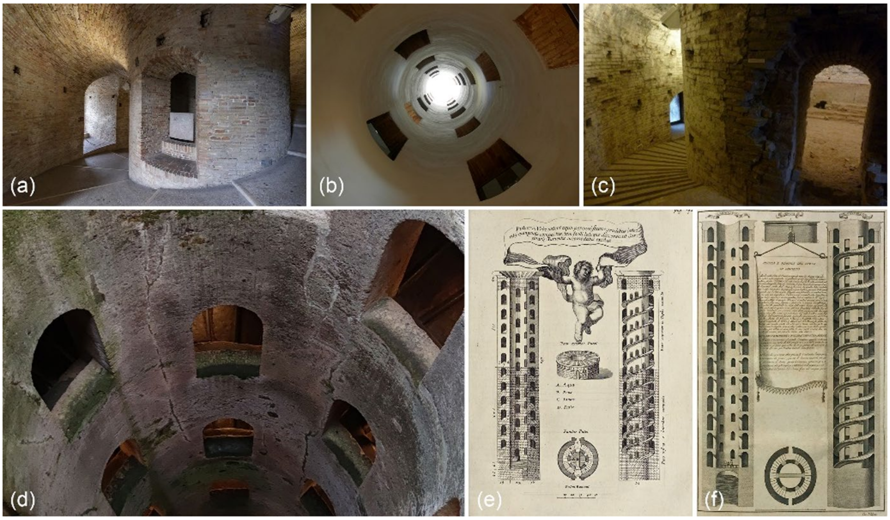


**Fig. 7** Helical staircases from the fifteenth and sixteenth centuries: **a** helical ramp in the ducal palace in Urbino by F. di Giorgio Martini (Image: Xavier de Jauréguiberry); **b** well of the helicoidal ramp in the monastery of St. Clare in Urbino by F. di Giorgio Martini (Image: Wikimedia Commons—CC 3.0—Limoncellista); **c** helical ramp in the ducal palace in Urbania by F. di Giorgio Martini (Image: Wikimedia Commons—CC 3.0—Limoncellista); **d** San Patrizio well in Orvieto by A. da Sangallo il Giovane (Image: authors); **e** plan and sections of the San Patrizio well in Orvieto (Image: Buonanni 1699: p. 192); **f** plan and sections of the San Patrizio well in Orvieto (Image: della Valle 1791)

different typologies: those with a solid central core, or in any case a core defined by prevalently continuous wall support, and those with an empty central core and steps supported by vertical punctual elements.

The first type includes several staircases built by Francesco di Giorgio Martini between the end of the fifteenth and the beginning of the sixteenth centuries in the ducal palaces of Urbino and Urbania, as well as those in the monastery of Santa Chiara in Urbino and the Rocca of Sassocorvaro. The double ramp example built by Antonio da Sangallo il Giovane for the San Patrizio well in Orvieto (1527–1537) is of the same type and has an even more significant historical impact. A commemorative coin was minted to mark the construction of this work, and its fame continued over time: the well is mentioned by Giorgio Vasari (1568: 318) and Egnazio Danti (Barozzi 1583: 143) and, later, the structure was published with plan and section drawings first by Filippo Buonanni (1699: 192) and again by Guglielmo della Valle (1791) (Fig. 7).

These structures mainly had service functions in large complexes or, as in the case of the Orvieto well, satisfied purely engineering needs by optimising accessibility and flows. Their evolution into aristocratic staircases occurred between the sixteenth and seventeenth centuries, giving rise to the type of staircase on pillars destined mainly for private pathways in palaces. This type derives from the progressive removal of the central supporting masonry and the adoption of shapes and details derived from helical staircases with columns orders in the central well, which had been meanwhile adopted as representative staircases in important palaces, such as


**Fig. 8** Helical staircases with central pillars from the seventeenth century: **a** staircase in Villa Aldobrandini in Frascati (1601–1602) by Giacomo della Porta (Image: Augusto Roca De Amicis); **b** staircase in Francesco Pelliccia's palazzetto in Via del Teatro della Pace in Rome (1615) by Onorio Longhi (Image: authors); **c** staircase in Palazzo Cenci al Pianto in Rome (1679) by Giovanni Antonio de' Rossi (Image: authors)

the circular helical staircases by Donato Bramante in the Vatican Belvedere (1507) and by Iacopo Barozzi da Vignola in the Palazzo Farnese in Caprarola (1559), those on an oval layout by Ottaviano Mascherino in the Palazzo del Quirinale (1583–85) and by Francesco Borromini in the Palazzo Barberini (1633) (Adorni 2016; Paris 2016; Paris et al. 2016; Paris and Valenti 2015). Following the influences of this latter noble type with columns, balustrades and mouldings appeared to ennoble the tradition started by Francesco di Giorgio Martini.

The forerunners in the Roman sphere of this new intermediate type were realised by Giacomo della Porta in the Villa Aldobrandini in Frascati (1601–1602) and by Onorio Longhi in the house of Bartolomeo Pelliccia at the Teatro Pace in Rome (1615). Both solutions are based on an oval plan and have the pillars positioned at the ends of their axes. However, if della Porta is to be credited with the innovation of the central core, it is Longhi who hybridises it by inserting a continuous balustrade taken from the nobler type of staircase with orders. The coexistence of the two overlapping elements, pilasters and balustrades, would later be solved by Giovanni Antonio de' Rossi in Palazzo Cenci al Pianto in Rome (1679), where the two elements alternate harmoniously (Tabarrini 2008: 79–92; Paris et al. 2016: 88–96) (Fig. 8).

## The Geometry of the Staircase in the Palazzo Spada Drawings

The circular helical staircase of Palazzo Spada was built in its peculiar form between 1657 and 1661, during the above mentioned typological evolution. Moreover, arguments on site management between the Spada family, Francesco Borromini and Francesco Righi arose and ended in design variations and the eventual collapse of a first staircase section during an advanced construction phase. This staircase is unique in the historical panorama for specific characteristics: the basement floors are of the hollow well type with continuous support, interrupted by small rectangular openings, while the above-ground floors are made of roughly trapezoidal pillars, with lozenge-shaped windows facing the central void; the pillars are not contained into the wall thickness but protrude into the central well with a completely original solution (Fig. 9).

Historical graphical sources regarding the palace are rich and refer to surveys and design hypotheses. Their comparison with the current survey allows to reconstruct the steps that led to the construction of the existing staircase.

The survey drawing of the first sixteenth-century layout (BAV, Vat. Lat. 11,258, f. 3), which also contains sketch drawings (Farroni and Mancini 2020: 55–66), confirms the initial presence of a small circular staircase that leans against the perimeter wall on Via del Polverone. The design drawing of 1650 for the enlargement of the palazzo attributed to Borromini (ASR, FSV, vo. 264, f.415) shows the first intention to introduce a larger circular staircase on Via del Polverone. However, if compared to the previous small staircase, this was moved towards the main garden. The next drawing attributed to Righi is dated 1657 (ASR, FSV, vol. 370, no. 46) and shows the abandoning of the circular shape in favour of an oval staircase placed even more towards the main garden.

This stair is more important than the previous project in size and geometric form. The transformation of the palace's grand staircase is also linked to this project (Tabarrini 2008: 35–37; Farroni and Mancini 2020: 47–68). Both projects by Borromini and Righi were not executed and the description and interpretation of the archival documents helps us understand the building site's progress and the client's choices (Tabarrini 2008).

Lastly, the drawing attached to Virgilio Spada's will of 1662 (drawing flat B on the piano nobile, ASR, Ospedale do S. Spirito, notary Sebastianus Sebenicus, vol. 343, c. 542, attached sheet on the recto 84–85 and the verso 82), already shows the current state with the circular staircase.

The comparison between the plan extracted from the survey data and the project drawings by Borromini and Righi, and the survey drawing attached to the Spada's will, highlight the geometric variations of the proposed solutions and the progressive definition of the final location of the staircase in the extension of the palace.

Righi's project drawing is fascinating (ASR, FSV, vol. 370, no. 46) as it seems to tell the story of the final stages of the process that evolved from the oval to the circular shape once the building site was underway. It shows two hand-sketched tangential circumferences inside the oval shape, with marks indicating the progression of the steps. These marks link the circumferences and not the development of the oval shape; therefore, it can be assumed that they succeed to the oval design.

Furthermore, it must be emphasised that the plan's dimension of the surveyed outer circumference is equivalent to twenty palms and is slightly smaller than the circumferences included in the oval. It corresponds to the sketch of a third circumference drawn in the staircase vestibule room, which remained hitherto

**Fig. 9** Palazzo Spada, helical staircase on Via del Polverone (Image: authors)

uncommented by scholars. The dimensions remarkably coincide with the central well's circumference and location within the extension on Via del Polverone.

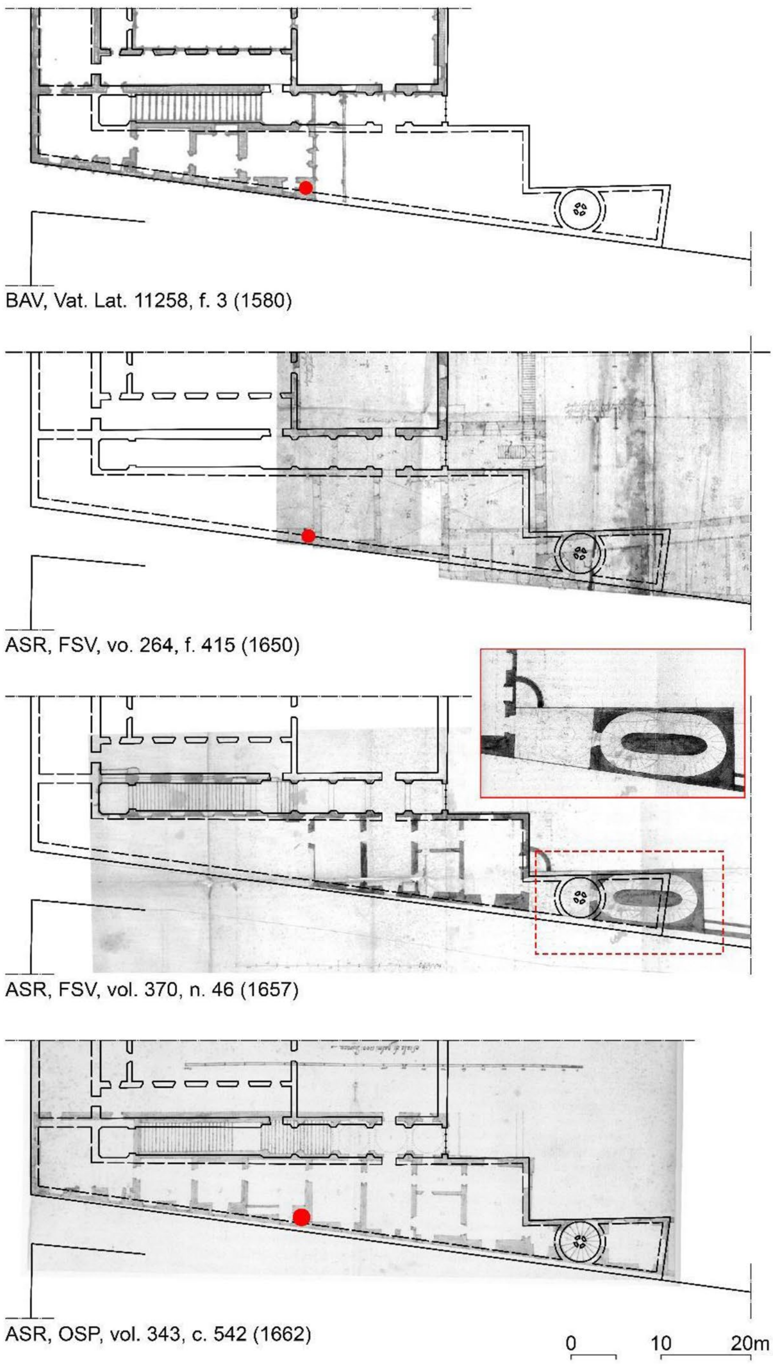


**Fig. 10** Comparison between the current state survey of the wing on Via del Polverone in Palazzo Spada with the circular helical staircase and the antique drawings. The red circle indicates the 16th-century helical staircase (Image: authors)

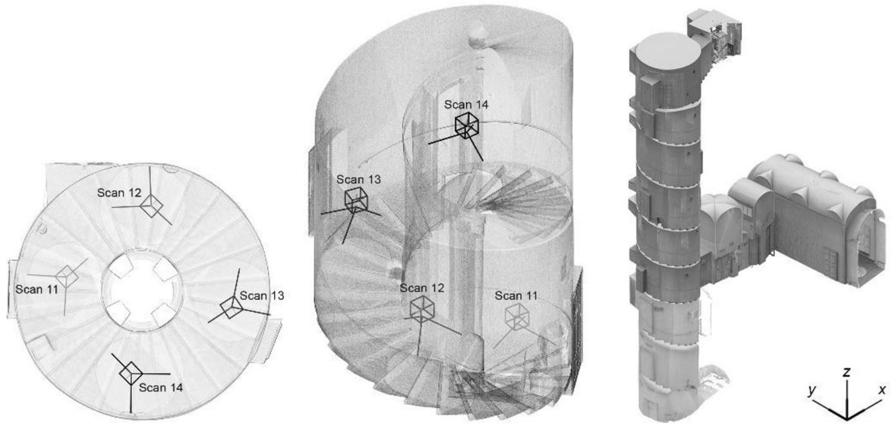


**Fig. 11** Extracts of the point cloud showing the survey pattern chosen for the circular helical staircase of Palazzo Spada. Point cloud of the entire staircase and access from the ground floor (Image: authors)

The correspondences between the present survey and the 1662 survey of flat B annexed to Virgilio Spada's will are almost perfect concerning both the staircase dimensions and its position (Fig. 10).

## The 3D Survey for the Scientific Reading of the Staircase

The survey of the helical staircase and the rooms accessed from the ground floor was performed using laser scanning techniques and the aid of univocal targets, distributed both along the external cylindrical wall of the room and on the central pillars. This solution avoided the possible alignment problems of the scans due to the repetitiveness of the geometries, the general lack of singular points caused by the absence of sculptural decorative elements, and the monochrome plaster finish. The survey pattern had to consider the shape of the staircase and the presence of important structural elements that occupy the central hollow well. For this reason, the scanning pattern is based on a series of four scans for each complete turn of the helix, positioned in correspondence with the openings of the central core, which allow a transversal view of the entire structure.

The survey model consists of 41 point clouds, totalling approximately 87 ml of points with an average alignment error of less than 6 mm for 99.9% of the points[3] and an average overlap between scans of 33% (Fig. 11).

Two-dimensional graphic documentation has been extracted from the three-dimensional survey, describing the entire staircase development in vertical and horizontal sections that correspond to the levels of the building's main floor.

[3] The scans were performed with a Z+F Imager 5010X laser scanner and subsequently aligned in Autodesk ReCap v.22.1.

The staircase reaches seven floors: two basement floors with service rooms, the ground floor, a mezzanine, two noble floors corresponding to the main residential flats, and an attic floor. The helical ramp makes seven complete turns in a clockwise ascending direction and consists of 171 steps, interrupted by five intermediate landings and one final landing, covering a total height of approximately 28.00 m.

The space containing the staircase has different dimensions, just as the width of the ramp and the central core are different for the basement and above-ground floors. The stairwell diameter in the basement floors measures an average of 4.18 m (eighteen and two-thirds palms), with a central core of 1.70 m (eight palms) and a ramp width of 1.24 m (five and one-third palms), while the thickness of the central bearing wall is 0.42 m (approx. two palms). The stairwell diameter in the above-ground floors measures on average 4.47 m (twenty palms), with a central core of 1.40 m (six and one-fourth palms) and a ramp 1.54 m (six and five-sixths palms) wide, while the radial thickness of the pillars is 0.32 m (approx. one and half palms[4]) (Figs. 12, 13).

## Survey Interpretation and Geometric Analysis

The two-dimensional representations of two characteristic horizontal sections of the staircase allow us to analyse the geometric proportions of the organism and compare it with the immediately preceding treatises.

The different structural typology adopted for the basement floors compared to those above ground is also reflected in a different geometric proportioning of the elements. Plan 2, adopted as a reference for the basement floors, presents a space subdivision corresponding to Andrea Palladio's Type B, who divided the space into seven equal parts (two and two-thirds roman palms each) and then assigned three parts to the central core (eight roman palms) and two parts to each side of the ramp (five and one-third roman palm each). On the contrary, Plan 6, used as a reference for the above-ground storeys, shows a room subdivision that corresponds to Andrea Palladio's Type A, so the room is divided into three equal parts (six and two-thirds roman palms each) and these are equally assigned respectively to the central core and the ramp on each side.

The structural and proportional discontinuity that emerges from the previous comparison also reads through the different geometric distribution of the openings in the central core between the basement and above-ground floors. Contrary to what one might imagine, the openings in the central cylindrical core of the basement storeys are only three and are not superimposed with any particular accuracy. On the other hand, the pillar solution of the above-ground storeys shows a more solid geometric structure: the sides of the pillars converge approximately towards the geometric centre of the stairwell and identify angles of 29° average amplitude,

[4] The conversions of these measurements consider the value of 22.34 cm per 1 Roman palm.

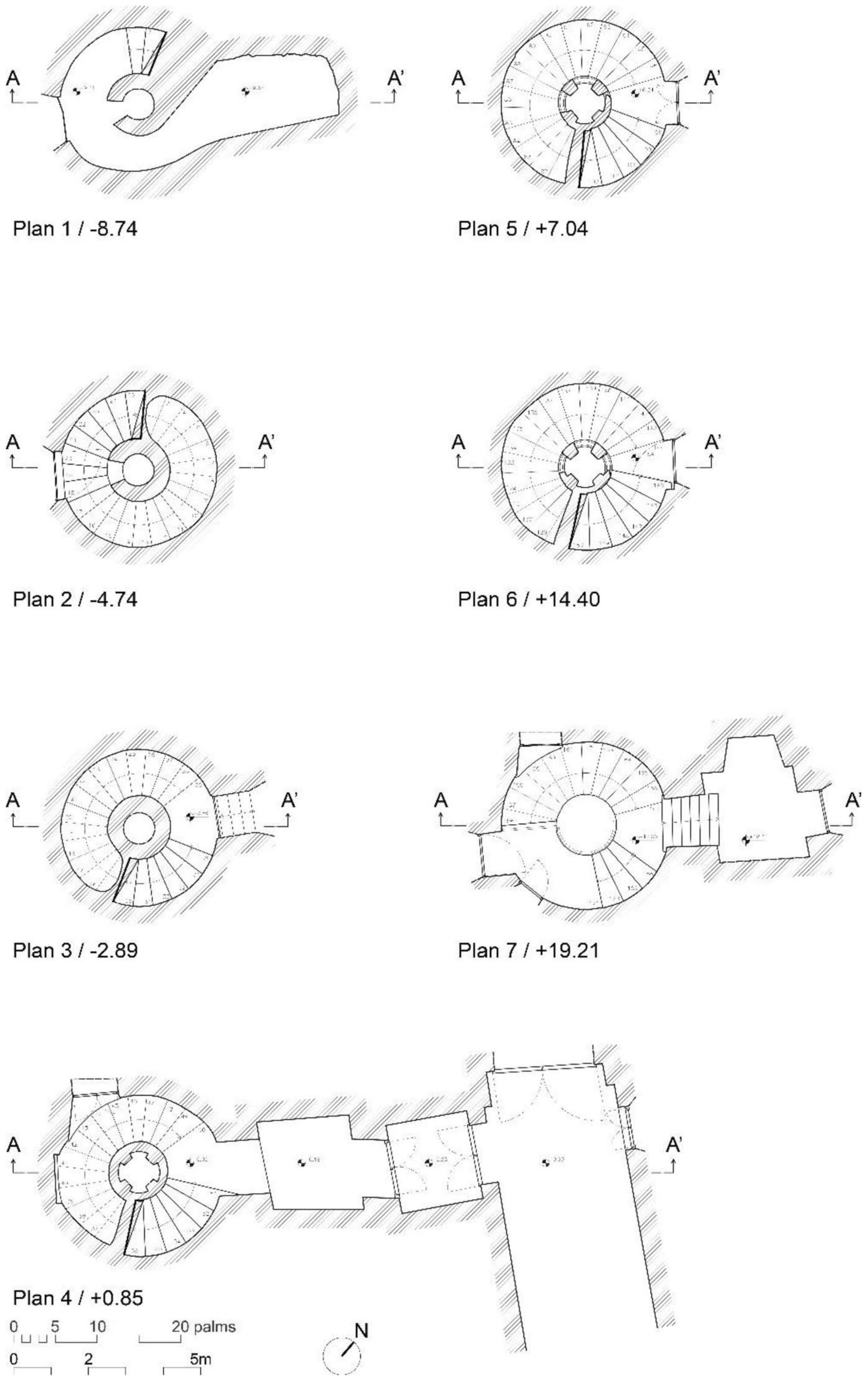


**Fig. 12** Survey, horizontal sections of the circular helical staircase (Image: authors)

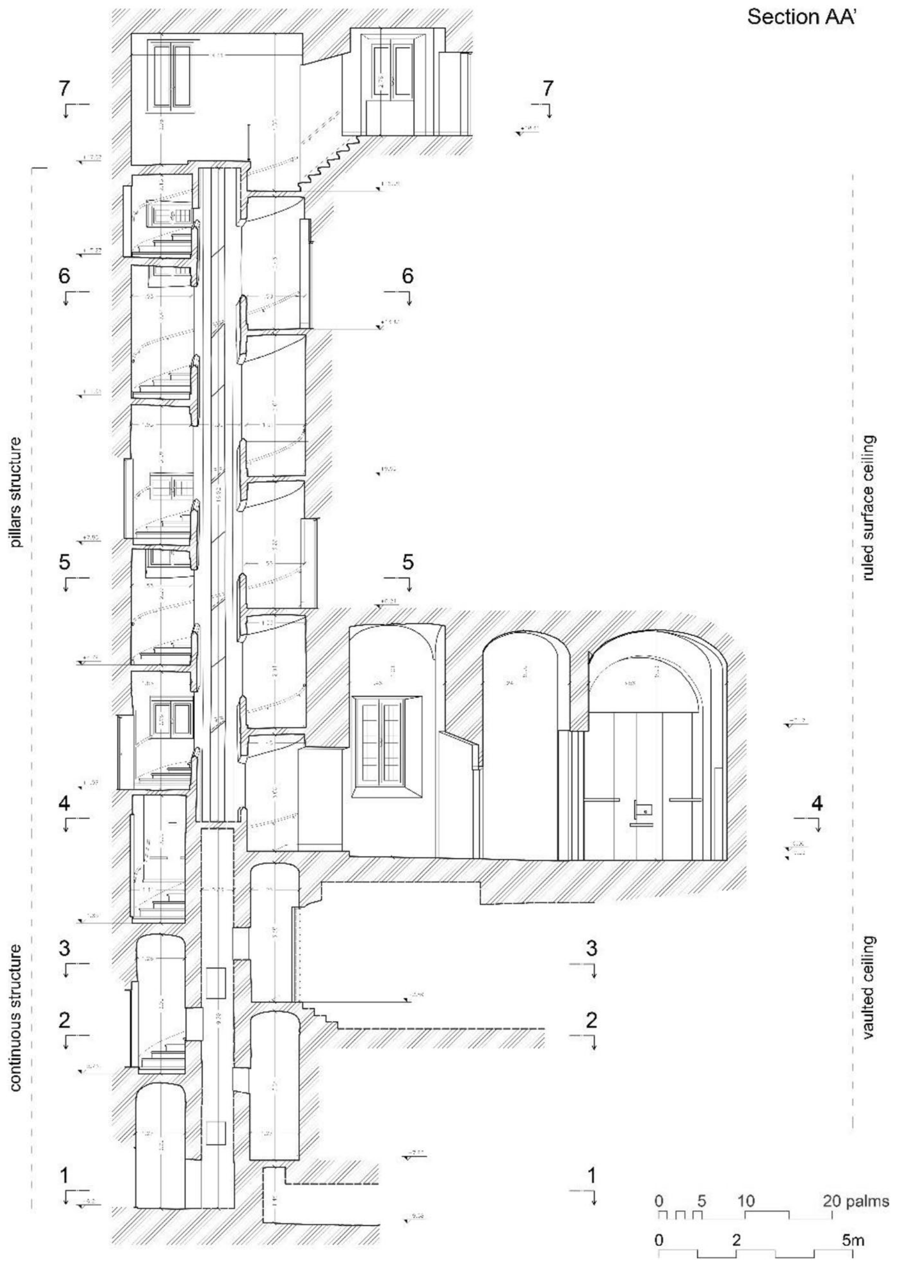


**Fig. 13** Survey, vertical section of the circular helical staircase (Image: authors)

divided by pairs of opposite sectors of different amplitudes in which the widest sectors, 62° and 70°, correspond to the sides where the landings are located (Fig. 14).

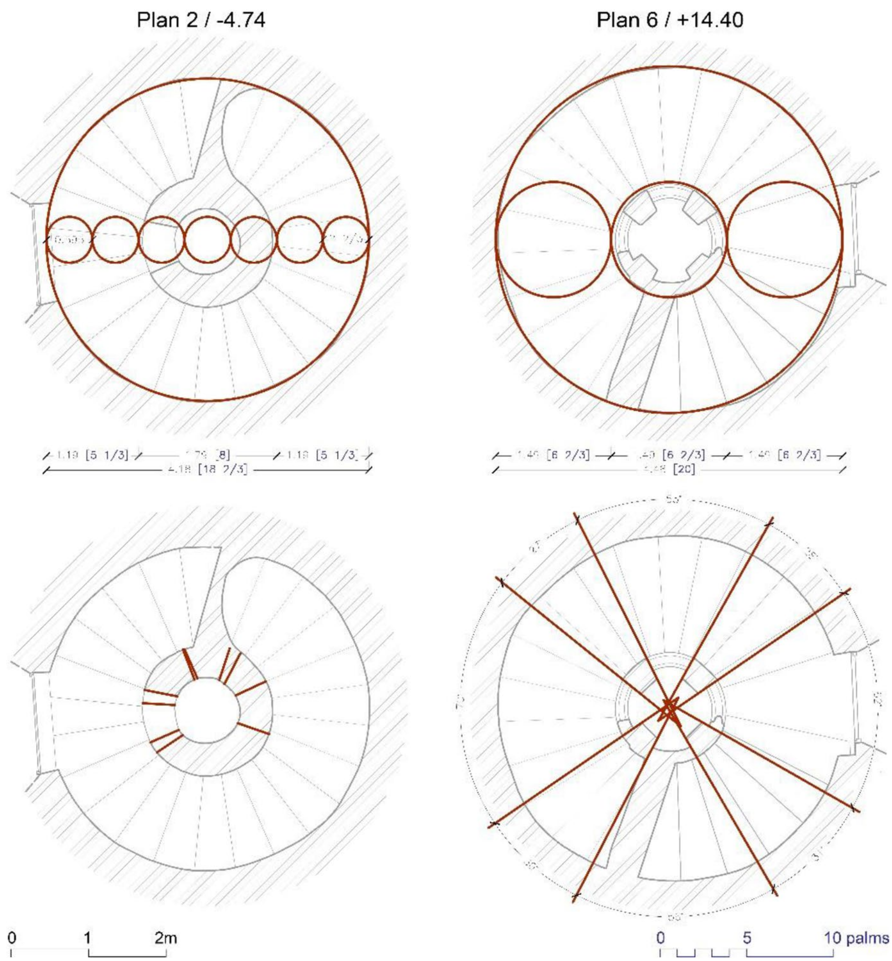


**Fig. 14** Proportional and geometric analysis of the circular helical scale with the comparison between dimensions expressed in meters and roman palms (Image: authors)

The three-dimensional survey and two-dimensional representations were used to build a model of the staircase consisting of continuous NURBS surfaces representing the artefact's constituent elements and their geometric properties. The model was reconstructed from the drawn sections (four vertical and sixteen horizontal) and from a set of roughly helical curved lines directly extracted from the point cloud through the interpolation of remarkable points. This set of curves was used as a skeleton for the construction of the surface, defining the main elements of the staircase:

- the hollow cylindrical central core of the basement storeys (a) and the four pillars supporting the ramp of the upper storeys (b);

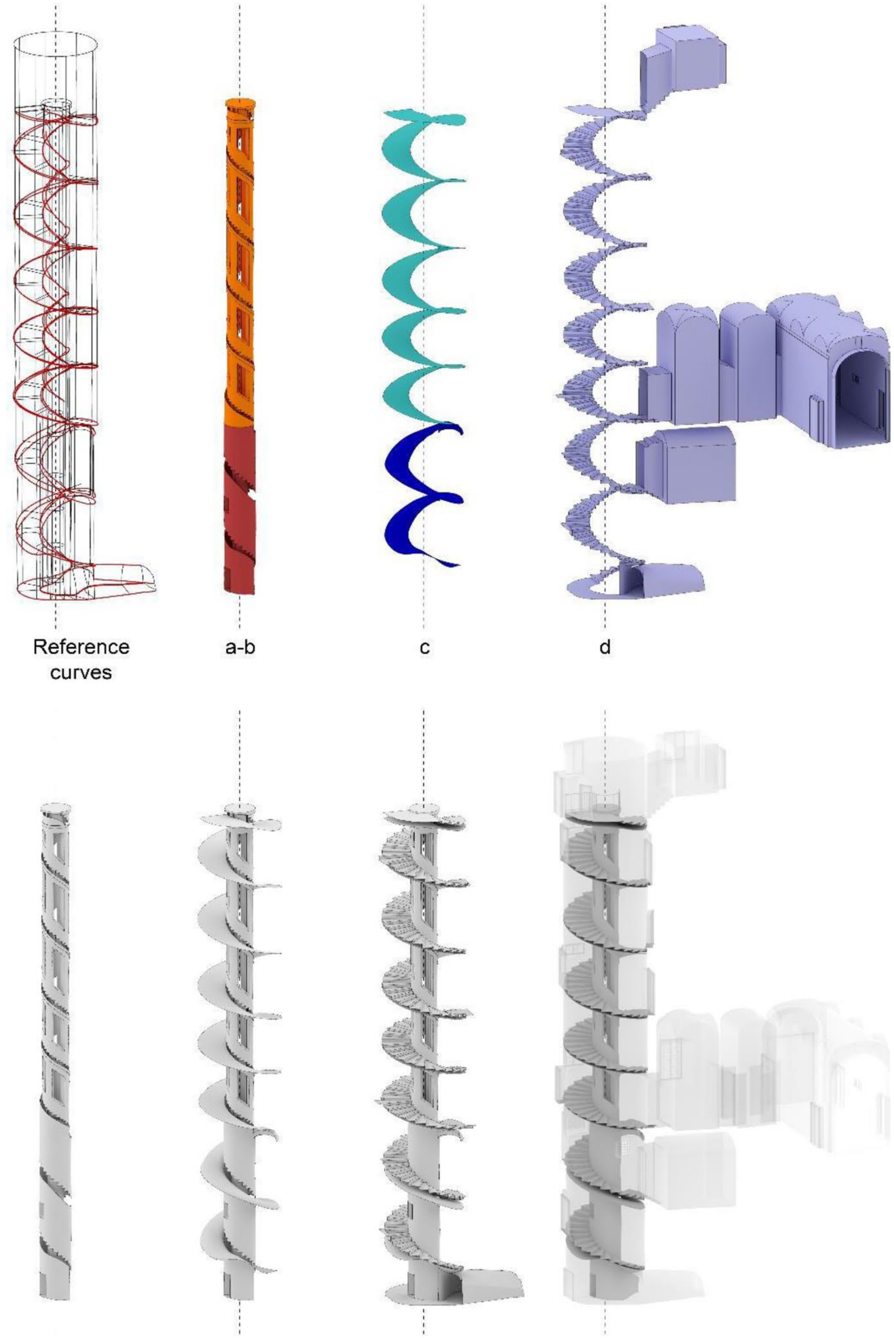


**Fig. 15** NURBS 3D model, the elements constituting the staircase and their aggregation: **a**, **b**, central supporting elements; **c** ramp intrados; **d** steps and landings (Image: authors)

- the intrados of the ramp, which in the basement storeys consists of a lowered annular vault and then transforms into a ruled surface close to a right helicoid (c);
- the extrados of the ramp consisting of steps and landings with the rooms facing directly onto the stairwell (d).

The three-dimensional interpretation of the survey clearly revealed the relationships between the individual elements that constitute the staircase and the variations undergone by the helical ramp to accommodate the different heights of the building's inter-floors (Fig. 15).

Three type turns (A–B–C) were identified to conduct further investigations focused on the slope of the helices (Paris 2019; D'Acunto et al. 2022). For each turn, four helices have been obtained by interpolation of points extracted from the point cloud with a NURBS curve, thus delineating the space of the staircase. The first pair of helices consists of the curves defining the course of the steps along the external wall and along the central core. The second pair defines the course of the ceiling, running at the lowered annular vault of the basement floors and, subsequently, along the edges between the ruled surface and the external and internal cylindrical walls of the compartment.

In order to normalise the layout of the identified curves and analyse their slope through their plane development, an algorithmic procedure has been defined to perform a series of operations on each curve. The algorithm extracts twenty points at a constant distance on the curve and projects them onto the horizontal reference plane XY. Then, it identifies the best approximation circumference of this set of points and extrudes it to describe the stairwell wall's best-fitting cylinder and projects the points extracted from the original curve onto the cylindrical surface according to the surface normal to trace an interpolated NURBS curve that belongs to the best-fitting cylindrical surface. Finally, the algorithm performs the plane development of the cylindrical surface and the previously reconstructed NURBS curve.[5]

The three turns (A–B–C) consist of 24 steps each, i.e., the number required to complete one full turn of the helix, are identified by the progressive number of steps. The plane developments of the analysed helices show: in red and orange, the outer and inner helices interpolate the steps; in blue and azure, the outer and inner helices interpolate the ramp ceiling. Given the geometric reference model of the cylindrical helix, which among other properties is both a rhumb and geodesic line of the surface, the expected plane development consists of straight lines. Due to the inevitable presence of approximations caused by the construction and the need to calculate the slope angle of the developed curves, it has been decided to sample twenty points on each developed curve and interpolate their positions with the best-fitting straight line. These straight lines were used to calculate the slope angle α of the helices that characterise the staircase of Palazzo Spada (Fig. 16). The first result highlighted by the developments is the close approximation of the geometric

[5] This procedure has been developed in Grasshopper for McNell Rhinoceros 7.

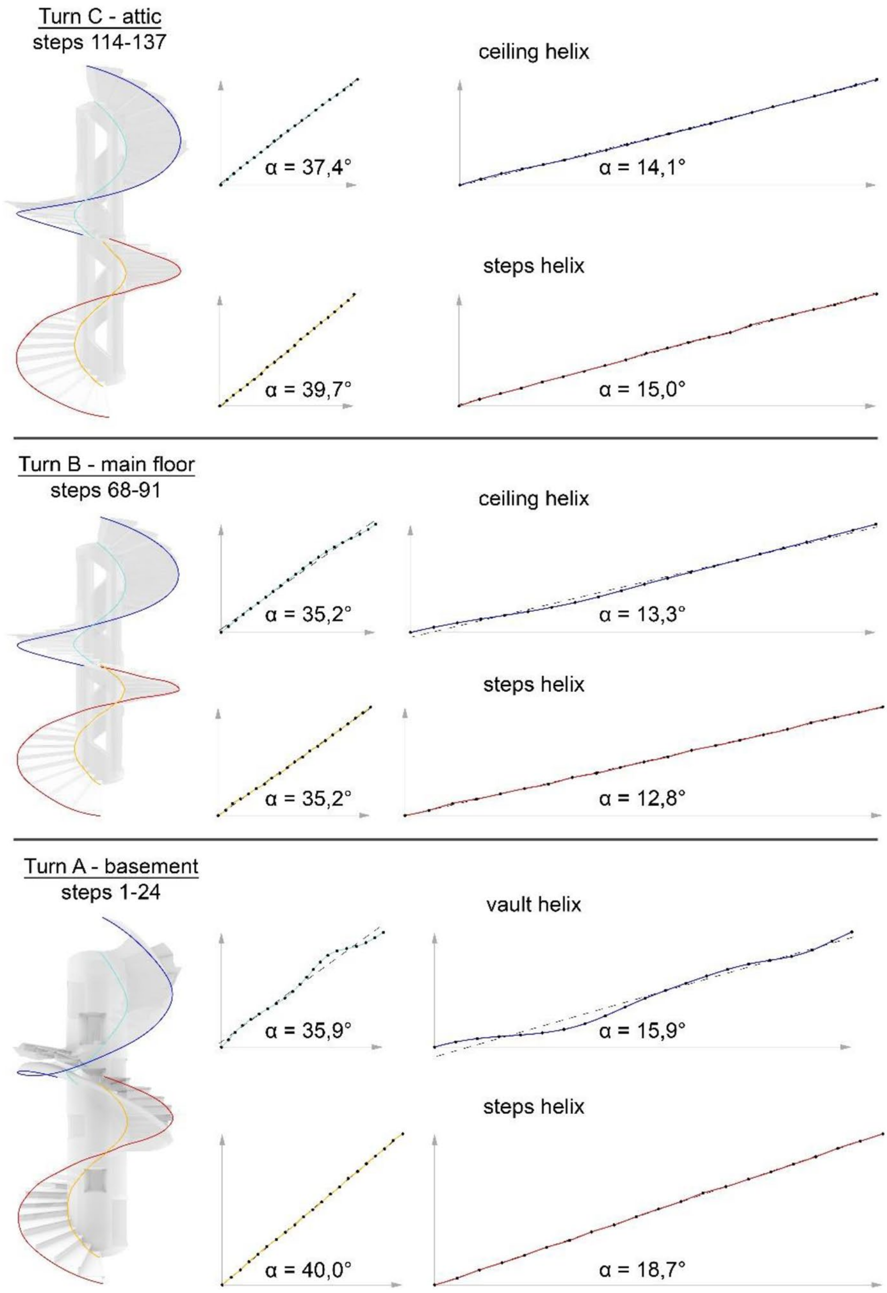


**Fig. 16** Study on the course of 3 turns (**A**–**C**): plane development of characteristic helices and calculation of the curve slope angle (Image: authors)

model of the cylindrical helix that characterises the realised staircase. This is particularly true for the helices interpolating the inner and outer course of the steps of all analysed turns and for the helices interpolating the ceiling of Turns B and C, which can be approximated to right helicoids. Only the helices representing the set of the Turn A lowered annular barrel vault show a more imprecise course, but this is undoubtedly attributable to the plaster finish of the surfaces in which an accurate definition of the vault set is challenging.

All internal helices have a greater slope than their corresponding external helices because they have a smaller radius for the same vertical pitch and, consequently, both greater curvature and torsion.

It is also evident how the slope variation characterises the staircase and how this is not distributed linearly along the vertical course of the ramp. Turn A, which starts from the building basement, is the steepest and therefore has higher riser steps than the other analysed turns. Turn B shows a significant softening of the slope, approximately by five degrees compared to Turn A, and is therefore characterised by lower steps that are well suited to the residential use of the floors served by this part of the staircase. Turn C, which is close to the end of the staircase and therefore to the rooms intended for servants, shows an increase in the slope of approximately two degrees compared to Turn B, indicating a progressive raising of the risers of the steps.

The helices developments of Turns A and C show another element that characterises the geometry of the staircase and, thus, its spatiality. In fact, helices of the steps and ceilings tend to converge, which generates a space compression if we travel up the staircase, or a space expansion if we travel down it. This effect is not, however, to be found in Turn B, where the developments are almost parallel. Although perceptible even to the daily user of the staircase, this peculiarity seems hardly attributable to precise design choices. In contrast, it would appear to be the direct consequence of the need to connect floors characterised by variable inter-floors (Fig. 17).

## Conclusion

Palazzo Spada's helical staircase was a central element in the design of the palace's extension towards Via del Polverone and saw a succession of projects and architects leading to the unprecedented solution that was finally built around 1660.

For the first time, the three-dimensional survey accurately establishes its metric and morphological properties, allowing to read both the structural variations of the central core—which transforms from a continuous support into a system of pillars—and those of the ramp ceiling—which change from a lowered annular surface to a ruled surface—as well as the extent of the pillars protrusion in the upper central well.

The analysis of its forms and geometries and the space it defines in its vertical twisting confirms its inclusion in the tradition of helical staircases for private use that characterised the Roman scene from the seventeenth century onwards, as already

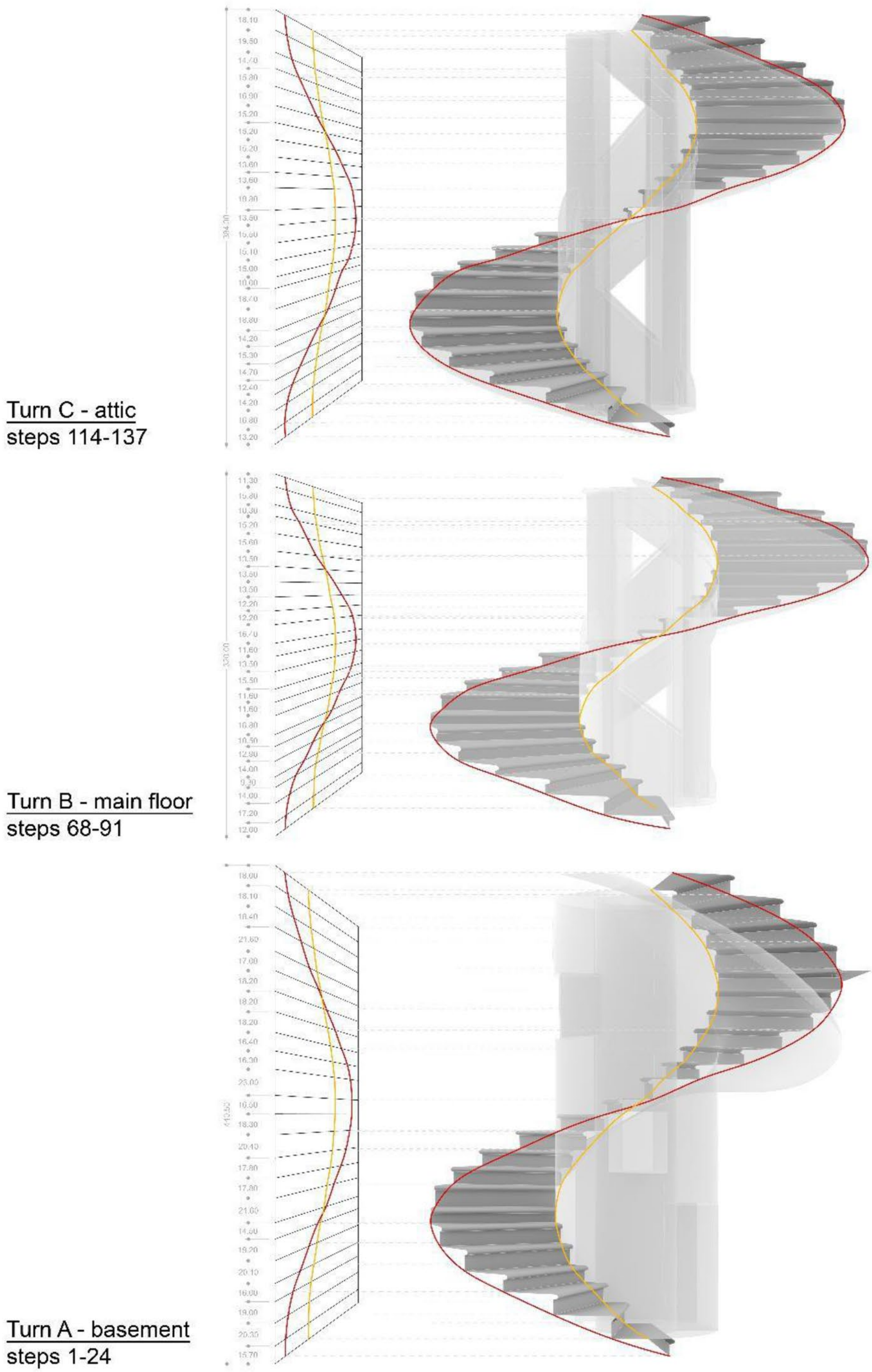


**Fig. 17** Study of the course of 3 turns (**A**–**C**): reading of the spatial configuration and step progression (Image: authors)

identified by prior historical research. Nevertheless, it describes its characteristics in a hitherto unpublished way. The proportions of the rooms and the relationships between ramps and central load-bearing cores demonstrate a direct descent from the schemes proposed by Andrea Palladio almost a century earlier in *I quattro libri dell'architettura di Andrea Palladio* (1570). The analysis of the slopes of the ramp and the ceilings shows the presence of variations due to the need to connect floors separated with different uses and inter-floors, which also generate specific vertical compression and expansion effects of the ramp's space.

The structure and spatial configuration of the staircase are an expression of the achieved organicity in the fruition of the palace rooms arranged at different heights, which were previously connected by a discontinuous path consisting of galleries, corridors, and service staircases. Considering their transformations over time, the close relationship between the staircase and the communicating rooms on the various floors will be the subject of a future in-depth study when the surveys of the floors are extended, supported by a specific investigation of archival documents.

A particular interdisciplinary in-depth study that we intend to undertake, based on the survey and geometric analyses presented here, concerns the static analysis of the unique structural solution with pillars protruding in the stairwell that characterises this staircase. In fact, this staircase seems to anticipate 'the technique of reinforced concrete' (Portoghesi 1982: 172) and it has already been considered a 'masterpiece of engineering' (Marconi 1967: 170) in the history of architecture.

Finally, the research extension with the survey and analysis of another helical staircase in Palazzo Spada, the oval-shaped one built by Francesco Borromini between 1653 and 1657, will allow to deepen our formal and technical knowledge of helical staircases in the seventeenth century. It also can help to reconstruct the complex system of internal, horizontal and vertical, routes that characterised the prestigious Roman palace at the height of its splendour, and that has now been lost due to the subdivision of the building between different institutions.

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## References


Adorni, Bruno. 2016. Bramante e le scale: dalla chiocciola della sagrestia di Santa Maria presso San Satiro a quella del Paradiso. Arte Lombarda, vol. 176/177, n. 1/2: 27–39.

Alberti, Leon Battista. 1565. *L'Architettura di Leonbatista Alberti tradotta in lingua Fiorentina da Cosimo Bartoli, Gentilhuomo, & Academico Fiorentino. Con la aggiunta de' Disegni*. Venezia: Francesco Franceschi.

Alberti, Antonio, Lezzerini, Marco, Parodi, Luca. 2015. Un'altra "torre pendente" a Pisa. Il campanile di San Nicola. In *VII congresso nazionale di archeologia medievale: Palazzo Turrisi, Lecce, 9–12 settembre 2015: volume 1*, eds. Paul Arthur, Marco Leo Imperiale, 111–116. Firenze: All'insegna del Giglio.

Bares, Maria Mercedes. 2007. La *vis de saint-gilles* del castello Maniace di Siracusa: un'audace sperimentazione di stereotomia. Lexicon, n. 4: 15–23.

Barozzi, Iacopo da Vignola and Egnazio Danti. 1583. *Le due regole della prospettiva pratica di M. Iacomo Barozzi da Vignola*. Roma: Francesco Zannetti.

Benítez Hernández, Patricia and Valiente López, Mercedes. 2015. The Tangent Solution to the Late Gothic Helical Staircase: A Justified Oblivion. Nexus Network Journal, 17: 379–398.

Blondel, Francois. 1698. *Course d'Architecture*. Paris: Blondel.

Buonanni, Filippo. 1699. *Numismata Pontificum Romanorum quae a Tempore Martini V. Tomus Primus* Roma: Dominici Antonii Herculis.

Calvo López, José and De Nichilo, Eliana. 2005. Stereotomia, modelli e declinazioni locali dell'arte del costruire in pietra da taglio tra Spagna e Regno di Napoli nel XV secolo. Tre scale a chiocciola a confronto: Castel Nuovo a Napoli, la Lotja di Valenzia e la Capilla de los Vélez a Murcia. In *Teoria e Pratica del Costruire. Saperi, strumenti, modelli. Theory and Practice of Construction Knowledge, means, models*, ed. Giovanni Mochi, 517–526. Ravenna: Edizioni Modena.

Chastel, André, Guillaume, Jean (eds.). 1985. *L'Escalier dans l'Architecture de la Renaissance actes du colloque tenu à Tours du 22 au 26 mai 1979*. Paris: Picard.

Cirillo, Vincenzo. 2018. La rappresentazione della scala nella trattatistica italiana dal XVI al XVIII secolo. diségno 3: 177–188.

D'Acunto, Giuseppe, Antonio Calandriello, and Enrico Caldo. 2022. Generative modeling as an alternative analysis tool for cultural heritage. The case study of helicoidal staircases. In *Architectural Graphics. Volume 1 – Graphics for Analysis*, eds. Manuel A. Ródenas-López, José Calvo-López, and Macarena Salcedo-Galera, 97–106. Cham: Springer.

della Valle, Guglielmo. 1791. *Stampe del Duomo di Orvieto dedicate alla Santità di Nostro Signore Pio Sesto Pontefice Massimo*. Roma: Lazzarini.

Farroni, Laura. 2019. *L'arte del disegno a Palazzo Spada. L'Astrolabium Catoptrico-Gnomonicum di Emmanuel Maignan*. Roma: De Luca Editori d'Arte.

Farroni, Laura. 2020. Connessioni su Palazzo Spada a Roma. In *CONNETTERE - Un disegno per annodare e tessere*, eds. Adriana Arena et al., 1139–1160. Milano: FrancoAngeli.

Farroni, Laura and Matteo Flavio Mancini. 2020. Accessibilità e prospettive visive: il ruolo dello scalone nobile di palazzo Spada nel XVII secolo. *Eikonocity*, anno V, n. 2: 47–67.

Guarini, Guarino. 1737. *Architettura civile del Padre D. Guarino Guarini chierico regolare*. Torino: Gianfrancesco Mairese.

Labacco, Antonio. 1559. *Libro d'Antonio Labacco appartenente a l'architettvra nel qual si figurano alcune notabili antiquita di Roma*. Roma: Labacco.

[Ms. 2173] Leonardo da Vinci. XV sec. *Manuscript B*. Paris, Institut de France.

Marconi, Paolo. 1967. La Roma del Borromini. Capitolium XII: 155–170.

[Fondo Nazionale, III.I.141] Martini, Francesco di Giorgio. XV sec. *Trattato di architettura*. Biblioteca Nazionale Centrale di Firenze.

Miles, Margaret M. 1998. Interior Staircases in Western Greek Temples. *Memoirs of the American Academy in Rome, 1998/1999*, vol. 43/44: 1–26.

Montano, Giovanni Battista. 1691. *Raccolta de Templii e Sepolcri disegnati dall'antico da Gio. Battista Montano Milanese. Libro Terzo* Roma: Gio. Giacomo de Rossi alla Pace.

Neppi, Lionello. 1975. *Palazzo Spada*. Roma: Editalia.

Palladio, Andrea. 1570. *I quattro libri dell'architettura Di Andrea Palladio*. Venezia: Domenico de' Franceschi.

Paris, Leonardo. 2016. La scala elicoidale a Caprarola di Jacopo Barozzi da Vignola. In *Le ragioni del disegno. Pensiero, Forma e Modello nella Gestione della Complessità*, eds. Stefano Bertocci, Marco Bini, 523–530. Roma: Gangemi.
Paris, Leonardo. 2019. La spirale cilindrica nelle scale rinascimentali e barocche. In *Le linee curve per l'architettura e il design*, eds. Laura De Carlo and Leonardo Paris, 145–170. Milano: FrancoAngeli.
Paris, Leonardo and Valenti, Graziano Mario. 2015. La scala elicoidale del Borromini a Palazzo Barberini: rilievo scan laser e modellazione parametrica. Disegnarecon, vol. 8, n. 15: 11.1- 11.11.
Paris, Leonardo, Maurizio Ricci, and Augusto Roca De Amicis. 2016. *Con più difficoltà. La scala ovale di Ottaviano Mascarino nel palazzo del Quirinale*. Roma: Campisano.
Portoghesi, Paolo. 1982. *Borromini nella cultura europea*. Bari: Laterza.
Scamozzi, Vincenzo. 1615. *L'idea della architettura universale, di Vincenzo Scamozzi architetto veneto. Divisa in X Libri*. Venezia: Per Giorgio Valentino.
Serlio, Sebastiano. 1545. *Il primo libro d'Architettura, di Sebastiano Serlio, Bolognese*. Paris: De l'imprimerie de Iehan Barbé.
Tabarrini, Marisa. 2008. *Borromini e gli Spada. Un palazzo e la committenza di una grande famiglia nella Roma barocca*. Roma: Gangemi.
Templer, John. 1995. *The Staircase: History and Theories*. Cambridge MA, London: The MIT Press.
Vasari, Giorgio. 1568. *Delle vite de' più eccellenti Pittori Scultori et Architettori Scritte da M. Giorgio Vasari Pittore et Architetto Aretino. Primo Volume della Terza Parte*. Firenze: Giunti.
Viscogliosi, Alessandro. 2000. *I fori imperiali nei disegni d'architettura del primo Cinquecento.* Roma: Gangemi.
Vitruvius, Marco Pollione. 1511. *De Architectura*. Venezia: Ioannis de Tridino.
Vitruvius, Marco Pollione. 1521. *De Architectura Libri Dece*. Como: Gotardus de Ponte.
Vitruvius, Marco Pollione. 1567. *De Architectura Libri Decem.* Venezia: Franciscum Franciscium & Ioan. Crugher Germanum.



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