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RESEARCH

Italian Architectural Ratios in the British Rotunda Typology

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Abstract

Stemming from centrally planned church architecture, the domestic rotunda type counts as one of the most renowned examples of Renaissance architectural conception. Often considered a physical and earthly manifestation of the divine, architects ordained rotunda symbolism through architectural ratio and proportion. While mostly linked to Italian examples, the rotunda typology also affected British architecture, as derived from the models of Serlio and Palladio. By combining 3D scanning and CAD analyses with historical methods, we scrutinise how commonplace architectural ratios shaped British rotunda plans in the cases of Hopetoun House and Chiswick House. At the same time, the architectural ratio proved a flexible tool to imitate and emulate Italian architectural models in its British context, making evident the richness and versatility of architectural models that British architects collated.

Keywords Architectural ratio · Sebastiano Serlio · Andrea Palladio · Lord Burlington · William Bruce · Rotunda typology

Introduction

The rotunda typology affected architectural conceptions during the Renaissance and reached a global zenith as seen in the examples of Thomas Jefferson's President's House (1792) and the multiple models found in Britain. The geometric purity of the rotunda type forms an ideal example for discerning the dissemination of architectural ratios during the early modern period. Moreover, the reading of architectural ratios allows us to understand the architectural models for this typology.

From Inigo Jones (1573–1652) onwards, twentieth-century British architectural historiography took Andrea Palladio (1508–80) as the prime influence in seventeenth-century Britain (Summerson 1953: 115; Wittkower 1974: 115–34, 155–76). Thus, Palladio's undisputed authority requires serious revision as

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recent research has revealed extra-Palladian influences in the British rotunda type (Girouard 2009: 299–376; Howard 1995a: 60, 79; Macaulay 1987: 4–9). To tilt Palladianism from its pedestal without dismantling its discourse, the present paper refines our understanding of British country house designs in which multiple architectural influences—primarily those of Sebastiano Serlio (1475–1554) and Palladio − intersect to create intellectual and localised designs.

After describing the working method, the paper first considers the prototype of the rotunda typology: the Pantheon in Rome. It next investigates Serlio's rotunda design for a royal house (c.1541–46) found in the manuscript housed in the Avery Architectural and Fine Arts Library (Serlio New York: pl. 43) and Palladio's Villa Rotonda (1567–92) as published in *I quattro libri* (Palladio 1570: II.18). It then contrasts the ratios found in Serlio's and Palladio's rotundas to William Bruce's (1630–1710) design of Hopetoun House as published in *Vitruvius Britannicus* by Colen Campbell (1676–1729) (Campbell 1717–25: II, pl. 75) and Chiswick House by Richard Boyle (1694–1753), 3rd Earl of Burlington and 4th Earl of Cork as published in William Kent's *The Designs of Inigo Jones* (1727: pl. 71). Thus, applied room ratios form a crucial part in understanding the architectural precedents for the creation of Hopetoun's and Chiswick's centralised plans. These rotundas act as the ideal cases for investigating grids, spatial sequences, functions, and room ratios.

Drawing Accuracy

Serlio's drawings were studied in person at the Avery Library whereas the data from the Digital Serlio Project allowed for a computer-aided design (CAD) analysis of Serlio's drawings (Digital Serlio Project 2018). Similarly, the University of Edinburgh Main Library's Special Collections holds the prints of Campbell, Kent, and Palladio which were 3D scanned. Based on these architectural media, this paper imposes a proportional analysis by scrutinising room ratios to unearth mathematical relationships beyond a mere visual comparison.

During the early modern period, commonplace conventions for measuring and proportioning architecture did not exist, and thus architects relied on their specific practices and knowledge that affected design typologies, wall thickness and architectural proportions. Whereas scholars legitimately accept that Palladio included the wall thickness in his ratios (Howard and Longair 1982: 128; March 2008: 229), the opposite holds true for Serlio, who measured the ratios within the boundaries of his walls, allowing for design flexibility (Rosci 1966: 61; Mols 2022). In Britain, the commonplace practice of incorporating wall thicknesses for spatial proportioning remains unknown. Yet, contemporary to Campbell and Kent, Isaac Ware's successful *A Complete Body of Architecture* (1756) hints at British construction and design practices with respect to wall dimensions (Summerson 1953: 337, 340, 438). Ware recommends that applying a variable wall thickness results from 'particular circumstances,' diminishing upper floor walls, and stems from the different climates of England and Italy (Ware 1756: 112, 115, 694). As such, British built practices relate more to Serlio's building rules rather than

Palladio's. Moreover, when looking at the scale bar and the described measurements on the plans of Kent and Campbell (Figs. 3, 4) it seems that their architectural ratios correspond to the room extremities and exclude wall thicknesses. Thus, the ratios as observed in this survey follow the applied practices and principles of Serlio, Palladio, Kent, and Campbell respectively.

The architecture prints of these four authors, all in a fair state, were studied in their original size derived from the first editions of their respective authors. Serlio described the physical architectural dimensions in the *Sesto libro*, whereas Palladio depicted his ratios in plan in *I quattro libri*; both volumes refer to dimensions in Vicentine feet. Following Palladio's example, Campbell's *Vitruvius Britannicus* imprints the predominant architectural ratios on his designs. Kent's *The Designs of Inigo Jones* omitted the room ratios of Chiswick's *piano nobile*; like Campbell, Kent measured his buildings in English feet. Yet, Kent enumerated physically tangible room ratios in Chiswick House's plan of the basement, providing a reliable point of departure for understanding the ratios of Chiswick's main floor. Since Campbell and Kent only included the main ratios, a CAD analysis based on a 3D-scanning survey verifies the room ratios of the omitted measurements. For example, the entrance hallways in Villa Rotonda do not exhibit all dimensions, and thus its ratios cannot be determined without a survey. These measurements follow the projections of the walls of adjacent rooms when applicable or are determined up to their extreme width or length when a wall does not clearly demarcate its boundary.

The most feasible way to scan architectural prints results from using handheld structured-light scanners and proves highly adaptive to CAD and prototyping (Carpo 2017: 120). The 3D scans of the respective prints of Palladio, Campbell, and Kent stem from using an Einscan Pro+ which surveys the measures and surfaces of the architectural prints. Released by Shining 3D, the Einscan Pro+ handheld HD mode registers 500,000 points per second with a single shot accuracy of 0.1 mm and a point cloud resolution of 0.2 mm. The scanner's accuracy and texture scan generate high-resolution 3D data of the architectural prints providing an optimised basis for transferring the point clouds into the 3D point cloud processing software CloudCompare. By applying scalar fields, CloudCompare extracts the required point clouds, and optimally suits the purpose of vectorial CAD transfer which enables the analysis of architectural ratios through VectorWorks (Fig. 1). This process allows for rectifying print or paper warping and helps to reconstruct the plans as originally intended, such as the perceivable inclination in Kent's plan of Chiswick House. The resulting images admit a comparative analysis of their respective ratios, emulated from the historic prints. Although 3D scanning devices have limitations, their micro-level accuracy remains more precise and efficient than traditional analogue surveying methods (Carpo 2017: 102).

Despite the unprecedented precision of 3D scanning devices, inaccuracies in prints and drawings still emerge due to the drawing deviations and nebulous woodcut techniques at the time of creation (Mols 2019). Similarly, paper degrades over time and shows signs of tearing, warping, and under the wrong conditions, even disintegrates. Customary surveying practices allow for an approximation error of 5% that considers both built and representational imprecision and help determine the precision of architectural drawings (Andrews 2009: 2.1.2). For example, English

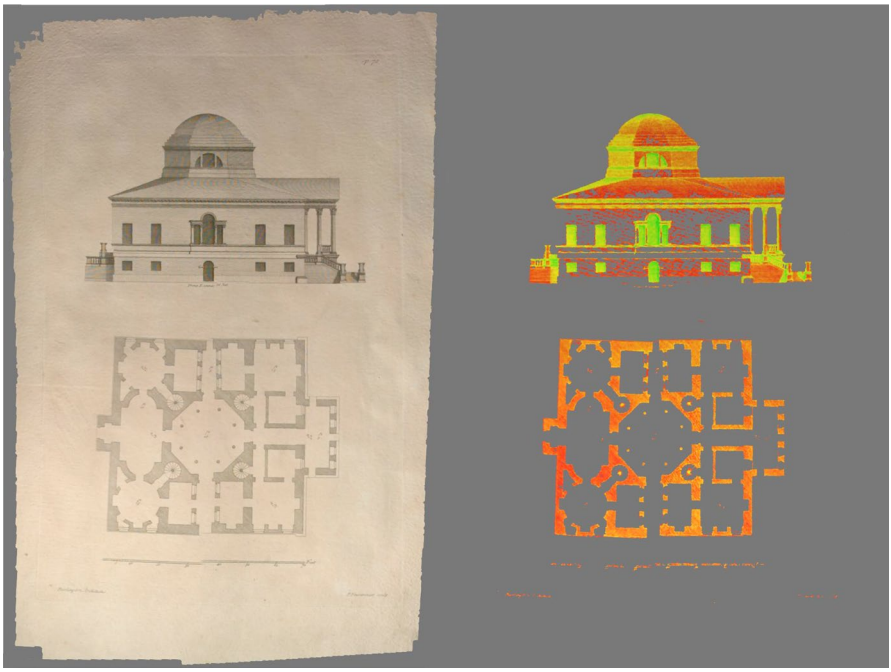

Fig. 1 Left Scan of Chiswick House. Image: Kent 1727: pl. 70; right the point cloud selection through scalar fields. Image: author

Heritage allows for a disparity of ± 5 mm for architectural surveys represented on a scale of 1:10, leading to an approximation error of 5% and up to 20% for large sites (Andrews 2009: 2.1.2).

For this inquiry, the 5% error forms the threshold for considering the measurements derived from the images of Serlio, Palladio, Campbell, and Kent accurate, despite the treatises depicting architecture at smaller scales than 1:10. Based on the smallest and the largest room measurements of each of these authors (the described measure) and by considering the line weight (the read measure) the approximation error of these drawings results (Table 1). The large-scale hand-drawn representations by Serlio show a line thickness of 0.25 mm whereas the others, being prints rather than drawings, include a 0.5 mm line weight. These measures result in mean approximation errors of 1.12% for Serlio (as the mean of 0.56% and 1.67%), 2.27% for Palladio (1.20%; 3.33%), 3.20% for Campbell (1.39%; 5.00%) and 1.57% for Kent (0.86%; 2.27%), all well below the acceptable 5% threshold. Thus, the prints allow for reliably comparing measured ratios across the treatises. Similarly, for comparing Serlio's and Palladio's ratios to the designs of Bruce and Lord Burlington, the 5% threshold error establishes the accuracy based on the decimal notation of architectural ratios and their approximation to the theoretical ratios found in Serlio's and Palladio's treatises.

The measured ratios in the surveys of Bruce's and Lord Burlington's designs have been approximated to commonplace architectural ratios from the early modern

Table 1 Approximation error of the architectural representations of Serlio, Palladio, Campbell and Kent

Treatise	Paper size	Described 'real' measure	Read 'real' measure	Line weight (mm)	Adjusted 'approximate' measure	Approximation error[a] (%)
English Heritage	1:10 scale	100 mm	100 mm	NA	105[b]	5.00
Serlio[c]	577 × 402 mm	L = 40 ft	45	0.25	45.25	0.56
		S = 12 ft	15	0.25	15.25	1.67
Palladio[c]	305 × 210 mm	L = 30 ft	41.8	0.5	42.3	1.20
		S = 11 ft	15	0.5	15.5	3.33
Campbell[d]	510 × 300 mm	L = 34 ft	36	0.5	36.5	1.39
		S = 10 ft	10	0.5	10.5	5.00
Kent[d]	516 × 372 mm	L = 40 ft	58	0.5	58.5	0.86
		S = 15 ft	22	0.5	22.5	2.27

[a]Approximation error calculated as (|real value − approximate value|/|real value|) × 100%

[b]English Heritage allows for a 5 mm deviation for 1:10 scales, the strictest measure upheld (see source)

[c]Measured in Vicentine feet

[d]Measured in English feet

period (March 1998: 272–77). Nevertheless, only the theoretical ratios that both Serlio and Palladio mention (1:1, 3:4, 1:$\sqrt{2}$, 2:3, 3:5, 1:2) are considered, along with Serlio's additional 4:5 ratio (Serlio 1545: fol. 21; Palladio 1570: I.53). As such, the survey's comparative drawings visualise the ratios and typologies while acting as the geometrical theorem of the analysis. The circles drawn in the plans below illustrate the ratios and indicate the approximation while outlining the inaccuracies of the architectural representations. Drawing and surveying tools only represent and approximate actual buildings, and measuring flawless accuracies remains unattainable. Nevertheless, the low approximation error and minimal deviation of the Serlian and Palladian ratios in the British rotundas make for a solid argument.

Models for the Rotunda Typology

The origin of the renowned rotunda villas traces back to the religious structures of the centrally planned church and antique examples (Wittkower 1967: 5). Yet, like no other, the Pantheon acted as the primordial archetype for the rotunda (Giaconi and Williams 2003: 128). Throughout history, numerous authors have depicted the Pantheon according to similar geometric configurations despite their different surveys (Fletcher 2019: 343). The scheme consists of two circles defined by the wall's outer perimeters and includes rotated squares circumscribed within the circular boundaries (Fig. 2). During the Renaissance, Serlio referred to the edifice as 'la Ritonda' (Serlio 1540: fol. v) whereas Palladio acknowledged it as 'la Rotonda' (Palladio 1570: IV.73). Both architects even revered the Pantheon for its morphologically perfect rotundity (Serlio 1540: fol. v) stemming from its

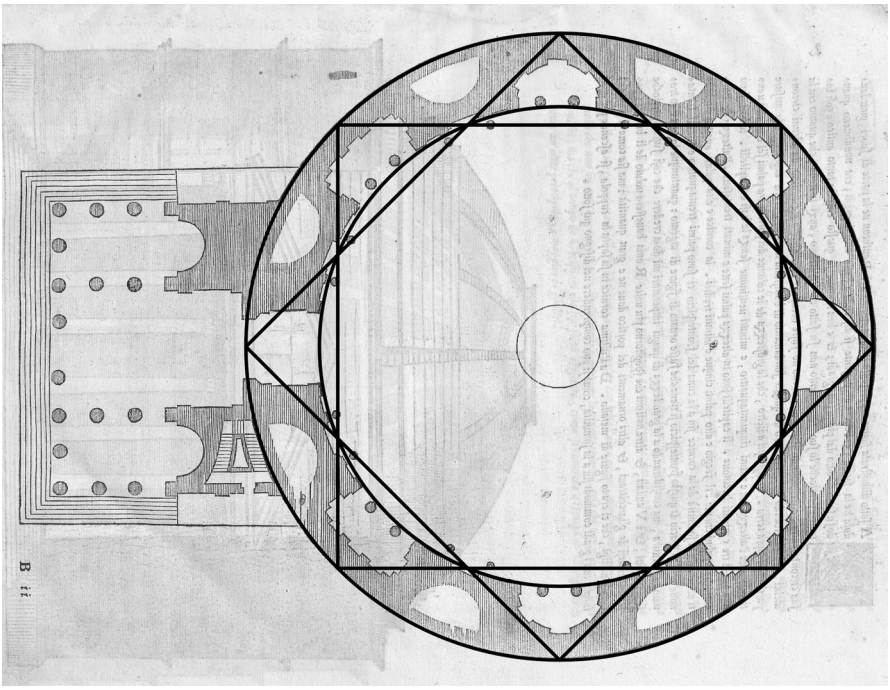

Fig. 2 Geometric diagram of the Pantheon. Image: Serlio 1540: VII. Image: author based on Fletcher 2019

mimicry of the spherical earth (Palladio 1570: IV.73). Ever since, the combination of the circular plan and dome has represented the divine heaven on earth (Tavernor 1991: 81). Indeed, such a divine-earthly analogy comes as no surprise since the glimmering transient light of the Pantheon's oculus guides the eye of the beholder to the heavens, illuminating the rigidity of the building with the luminous ethereality of the skies. Yet, this realisation was only made possible due to the purity of its numerical proportions (Wittkower 1967: 7), underlining the pivotal role ratio and proportion played in grasping the rotunda type.

Beyond the antiquities, Leon Battista Alberti (1404–1472) Christianised such rotundity by perpetuating the false yet popular belief that antique temples were mostly centralised, with the Pantheon's conversion to a church as one of the most famed examples (Alberti 1485: VII.4; Campbell 2023 preprint: 16). Soon after, numerous Renaissance architects adopted the typology for domestic architectural designs, as seen in Francesco di Giorgio's (1439–1502) centralised villa schemes, Andrea Mantegna's house in Mantua (c.1502), and Giovanni Maria Falconetto's Odeo Cornaro (1524) (Tavernor 1991: 22, 81–83; Campbell 2023 preprint: 5–6). With the writing of the Munich manuscript between 1547–1550, Serlio linked the house to the temple in which his 'new form of lodging… resembles the temple more than a house' (Serlio Munich: fol. 35v; Rosenfeld 1978: 25). Thus, Serlio relates the rotunda to the divine as per Francesco di Giorgio's earlier schemes, known to Serlio as his own teacher, Baldassare Peruzzi (1481–1536), was trained by Francesco di

Giorgio (Wittkower 1945: 73; Onians 1988: 176). Astonishingly, Serlio formulated his rotunda types slightly before Palladio's inventions from the 1550 s, including the design for the unfinished Villa Trissino Meledo di Sarego (c.1558–62) and the Villa Rotonda (1566–69) (Giaconi and Williams 2003: 100, 128). Hence, when asserting the British rotunda type, we must endorse Serlio's designs alongside Palladio's.

Vincenzo Scamozzi completed Palladio's unfinished Villa Rotonda in 1592 and worked on comparable developments, including the Rocca Pisana in Lonigo (1575–78) and the Villa Bardellini in Monfumo (1594–1600) (Kubelik 1986: 105). Thus, Scamozzi's designs could have acted as precedents for British rotunda types beyond the examples of Serlio and Palladio. British architects possibly relied on various other models, including the books of Jacques Androuet du Cerceau (1510–84) and Pierre le Muet (1591–1669) (Rosenfeld 1978; Campbell 2015). French examples that derive from Serlio's royal house include Jean Marot's *Petit Marot* (1659) and the Château de Marly in Marly-Le-Roi, (c.1679–84), built by Charles le Brun and Jules Hardouin-Mansart for Louis XIV (Stewart 2016: 34, 216–17, 304; Hartmann 2012). By the time le Brun and Hardouin-Mansart built Marly, the Avery manuscript containing Serlio's rotunda was still in France (Campbell 2022: 4, 6), and plausibly served as a basis for Marly's design. Marly also shaped British architecture, as William Adam's *Vitruvius Scoticus* includes a design by John Erskine, Earl of Mar, for a Royal Palace (c.1728), naming it a 'plan of which is after the manner of the same bigness of the royal pavilion at Marly' (Adam and Simpson 1811: 109–10; Stewart 2016: 216–17, 304).

In Britain, the rotunda typology affected the designs of Mereworth Castle (1723–35), Chiswick House, Nuthall Temple (1757) and Foots Cray Place (1757) (Ackerman 1990: 149–50). Of these, Lord Burlington's Chiswick is arguably the most famous (Wittkower 1974: 90, 104–05). Burlington initiated the neo-Palladian movement, which exerted influence on English architects (Wittkower 1974: 90, 104–05). Soon the villa became a principal subject of British architectural writing; the publications of Colen Campbell, James Gibbs (1682–1754), William Kent, and William Adam revolved around the domestic type, and all included rotunda-inspired plans (Harris and Savage 1999: 94–104, n. 8). The recent discovery that Serlio's Avery manuscript for the *Sesto libro* circulated in Britain around 1700 urges for the reframing of how the British rotunda type evolved (Rosenfeld 1978: 27; Campbell 2022: 10). Like other manuscripts and drawings, a rarity such as the Avery manuscript must have enticed English and Scots alike to study its drawings. In what follows, the analysis only focuses on the pivotal examples of Serlio and Palladio.

Serlio's and Palladio's Rotunda Plans Compared

Palladio's Villa Rotonda (Fig. 3) and his published project for the Villa Trissino at Meledo (Palladio 1570: II.60) count perhaps among the highest achievements of Renaissance planimetric perfection (Wittkower 1967: 75). Palladio's plan resembles prior rotunda archetypes, such as the Odeo Cornaro, but Palladio's design exhibits greater symmetry than its precedents (Tavernor 1991: 80, 82). The lowermost

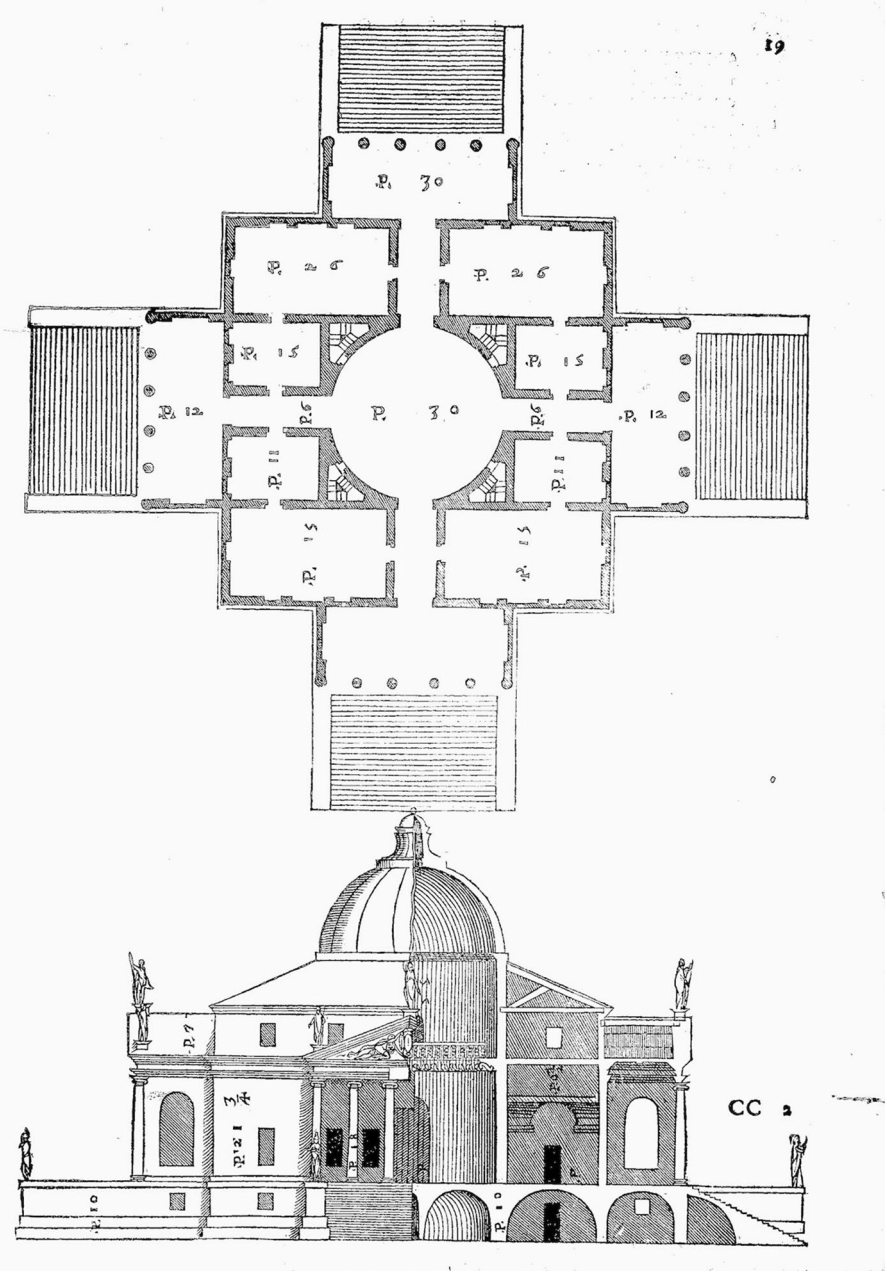

Fig. 3 Plan of Villa Rotonda. Image: Palladio 1570: fol. 19

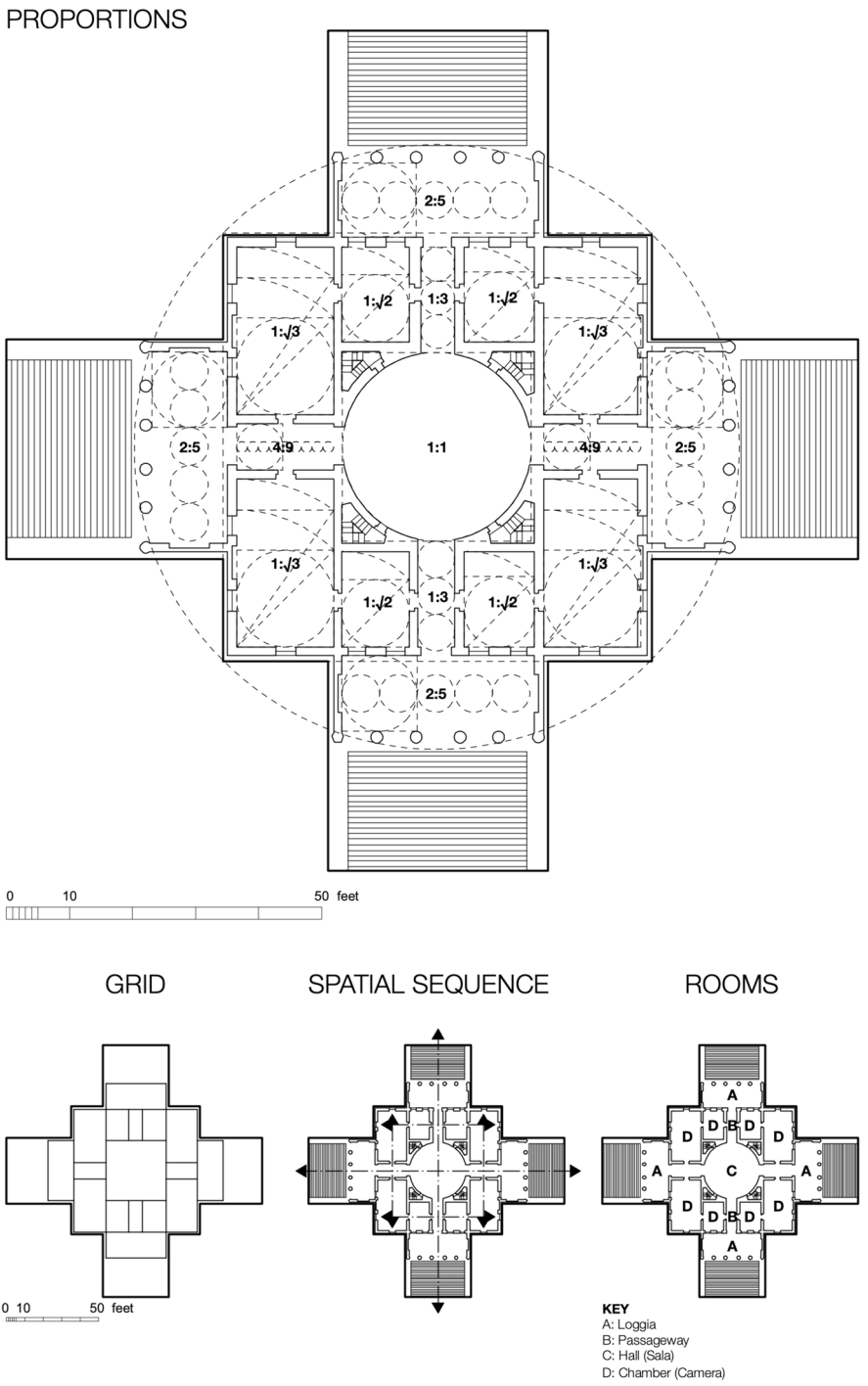

Fig. 4 Analysis of Palladio's Rotonda. Image: author

Table 2 Approximation error of Palladio's Villa Rotonda with theoretical ratios

Real measure (ft)	Decimal value	Theoretical ratio	Decimal value	Approximation error
12×30	0.4000	2:5	0.4000	0.00%
15×26	0.5769	1:$\sqrt{3}$	0.5773	0.07%
11×15	0.7333	1:$\sqrt{2}$	0.7071	3.57%
30×30	1.0000	1:1	1.0000	0.00%
5×15[a]	0.3333	1:3	0.3333	0.00%
7×15[a]	0.4667	4:9	0.4444	4.78%
				1.40% mean

[a]Measured in CAD

diagram of the Rotonda shows the grid of Palladio's design based on the centre-to-centre distance (Fig. 4).

For the spatial sequence of the Rotonda, Palladio positioned the doors in the middle of the rooms, creating vistas. Biaxial vistas run from the loggias through the central hall, connecting the exterior to the interior of the house. The inner views, which bisect the rooms, always end on a window, create a visual indoor-outdoor relationship, and result in a transparent and open spatial hierarchy. Palladio positioned the public functions of the house in the central hall and loggias, with the more private rooms located in the corners. Except for the circle, and the 1:2 ratios for the vestibules, Palladio did not use the ratios he recommended in *I quattro libri* consisting of the circle, 1:1, 1:$\sqrt{2}$, 3:4, 2:3, 3:5 and 1:2 (Palladio 1570: I.52, 54; Mitrović 1990: 279–92). Moreover, numerical rounding becomes inevitable when taking in account the scale of the design. The decimal notation of Palladio's 11:15 ratio and the recommended 1:$\sqrt{2}$ ratio relate to 0.7333 and 0.7071 respectively, exhibiting an approximation error of 3.57% (Table 2) (Palladio 1570: I.52). The four corner rooms (15:26 = 0.5769) approximate a 1:$\sqrt{3}$ (0.5773) ratio which specifies a viable approximation with an error of 0.07% (Mitrović 1990: 285–86). Overall, Palladio's mean error of 1.40% leads to a difference of 14 mm per 1 m, resulting in a difference of 1.000 cm versus 1.014 cm for a scale of 1:100. While these numbers differentiate, when drawn to scale, the differences between these ratios become negligible and unperceivable in the built edifice.

Similarly, Serlio's rotunda plan for a royal house exhibits an equally great symmetry (Fig. 5). The axial symmetry, the central hall, and the smaller rooms between the entrances and the larger corner rooms stem from Serlio's measured drawing of the Odeo Cornaro (Serlio 1575: 5, 219; Spallone and Vitali 2019: 313). In his design, Serlio strictly adheres to three (1:1, 2:3, 1:2) of the seven rectangular-derived ratios as published in his treatise (1:1, 4:5, 3:4, 1:$\sqrt{2}$, 2:3, 3:5 and 1:2) (Serlio 1545: fol. 21; Spallone and Vitali 2019: 309). The mean approximation error observed in the royal house's room ratios reckons to 1.79% (Table 3), persuasively connecting the measured ratios of Serlio's rotunda to his theoretical principles. While both the scale and the façade of Serlio's edifice distinguish themselves from Palladio's, the plans show great resemblance. The grid, based on the centre-to-centre dimension of the walls, shows great similarity to that of the Villa Rotonda with a

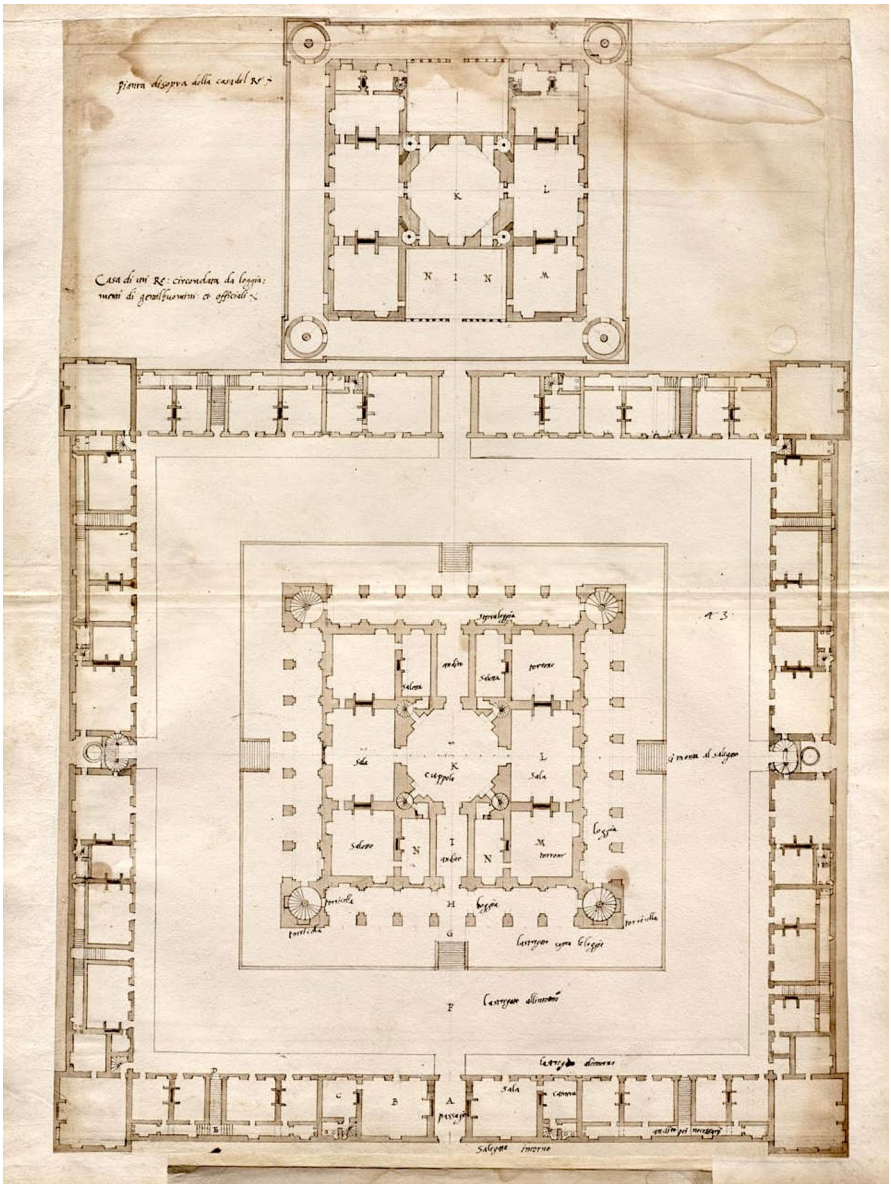

Fig. 5 Plan of a royal house. Image: Serlio New York: pl. 43

central square of an otherwise two-directional triple-piled building (Wittkower 1967: 70). Due to the close resemblance between the plans of Serlio and Palladio, Serlio's influence on Palladio seems more obvious than Palladio copying the Odeo Cornaro (Tavernor 1991: 22, 81–83). Nonetheless, the shapes of the four apartments, one in each corner, diverge between the respective designs. Moreover, Serlio designed a

Table 3 Approximation error of Serlio's royal house with theoretical ratios

Real measure (ft)	Decimal value	Theoretical ratio	Decimal value	Approximation error
12×110	0.1091	1:9	0.1111	1.83%
27×27	1.0000	1:1	1.0000	0.00%
40×40	1.0000	1:1	1.0000	0.00%
27×40	0.6750	2:3	0.6667	1.23%
13×25	0.5200	1:2	0.5000	3.85%
13×27	0.4815	1:2	0.5000	3.84% 1.79% mean

loggia around the house with four majestic spiral stairs. Due to the smaller domestic scale of Palladio's dwelling in contrast to Serlio's royal house, the smaller centrally positioned stairs sufficed for circulation.

Comparing the circulation patterns and the resulting spatial hierarchy (Fig. 6), a vital difference emerges between Serlio and Palladio. Serlio's public rooms include the loggias (A) on all four sides, with the octagonal *sala* (C) forming the main room while also containing smaller halls (F) (Hersey 1976: 53). In both designs the two central perpendicular axes organise all public functions by centrally placed doors, creating indoor-outdoor vistas with the same transparency and interior/exterior relationship (Wittkower 1967: 70). The corner apartments function as private rooms consisting of chambers (D) and rear rooms (E). Palladio mimicked these compositions, however, where Palladio positioned doors in the middle of the room's walls, Serlio put fireplaces. Thus, Serlio's circulation route takes an off-centre position without creating inner vistas. Despite not creating the same spatial openness as Palladio's plan, one cannot consider Serlio's design decision inferior. Rather, Serlio's system allows privacy in the apartments by visually shielding the central part of the rooms, and by doing so, aims at their domestic use. Thus, Serlio clearly distinguished a spatial sequence between the public and the private functions in his designs.

When relating Serlio's royal house with its circular diagrams and revolved squares to the Pantheon scheme (cf. Fig. 2) a striking similarity comes forth and reinforces the hypothesis that Serlio drew inspiration from the Pantheon. Hence, Serlio's royal house seeks a natural order, not only through harmonious ratios but also through the spatial sequence. The octagonal hall and dome insinuate the heavens, and the central axis creates an outdoor vista that connects the house to the natural world outside (Wittkower 1967: 29). On similar rotunda schemes, Serlio even stated that *Questa havera piu forma di tempio che di casa per alontanarmi da quello che tut[t]o il giorno si costuma* (this [house] has more the form of a temple than a house to distinguish it from everyday custom) (Serlio Munich: fol. 35v). Serlio's statement recalls the celestial references, common in Renaissance architecture, associated with Palladio's Villa Rotonda which thus took possible inspiration from Serlio's morphologies (Wittkower 1945: 73). Moreover, Serlio's rotunda unveils that Palladio's Rotonda links more to Serlio than to the Casa Mantegna and the

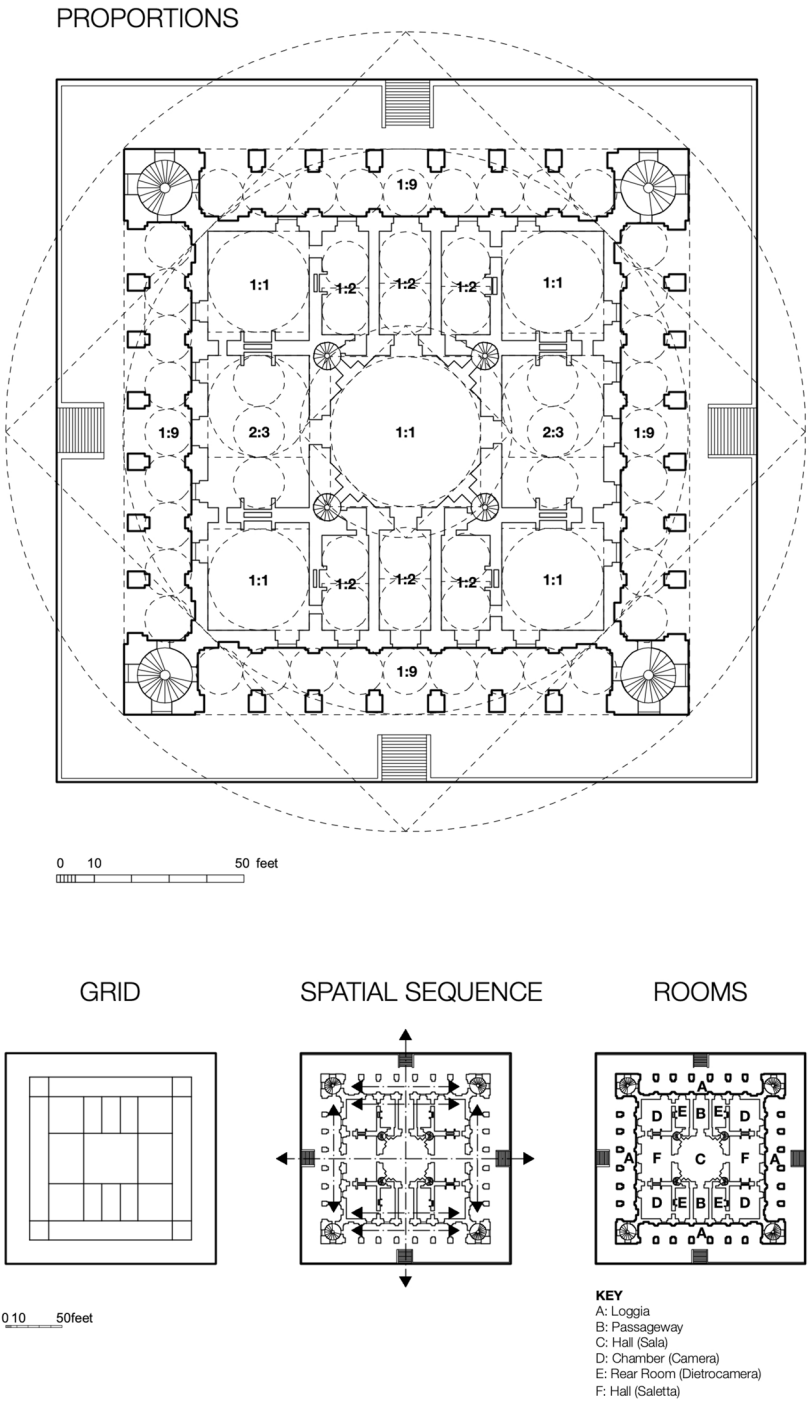

Fig. 6 Analysis of Serlio's Royal House. Image: author

Odeo Cornaro. Since Palladio designed his rotunda types from the mid-late 1550 s onwards (Giaconi and Williams 2003: 100, 129), he did not devise his centralised inventions before Serlio, who had already died in 1554.

William Bruce's Hopetoun House

Charles Hope, first Earl of Hopetoun, commissioned the Scottish Palladian Hopetoun House (1699–1756) (Adam 1811: 28; Colvin 1995: 151–55) to architect William Bruce, who is renowned for bringing the classical style to Scotland, first seen in the Palace of Holyroodhouse, 1671–78 (Lowrey 2020: 96). Bruce's Hopetoun House counts among the first centralised plans of Scotland, and many scholars have alluded to Serlio's influence, including designs presented in the *Sesto libro* (Howard 1995b: 59; Basset 2020: 111, 144; Lowrey 2020: 95–6).

Commonly acknowledged models for the house refer to French examples such as Marot's *Petit Marot* or the Château de Marly (Macaulay 1987: 21; Howard 1995a: 58). Yet, Hopetoun's design resembles the compositions, hierarchies, and proportional applications of Serlio and Palladio's designs, even though it technically does not count as a rotunda type due to its longitudinal arrangement. Today's Hopetoun mostly stems from William Adam's extensions of 1721–48, with altered interior designs by Robert and John Adam dating to 1750–56 (Adam and Simpson 1811: 28; Colvin 1995: 151–55) (Fig. 7). In contrast, the earlier plan by William Bruce, as published in Campbell's *Vitruvius Britannicus* (Fig. 8), shows the original rotunda design from c.1699–1703 with the additional flanking wings of c.1706–10 (Campbell 1715–25: II.4; Rowan 1984: 184; O'Hara 2010: 104). Campbell spoke highly about the house and its designer, stating Bruce 'was justly esteem'd the best Architect of this time in that Kingdom' while the design included 'four very handsome Apartments' which Campbell described as 'well finished and

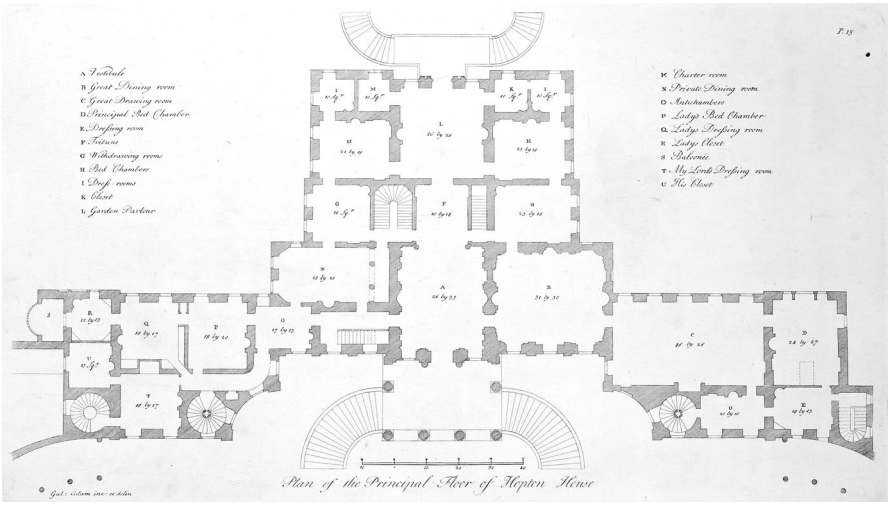

Fig. 7 Plan of Adam's alterations of Hopetoun House. Image: Adam and Simpson 1811: pl. 15

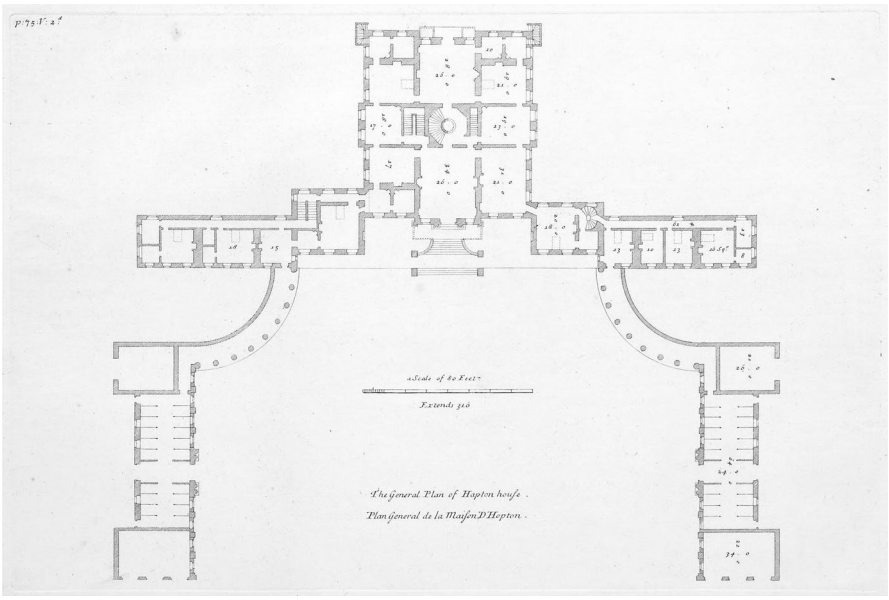

Fig. 8 Plan of Hopetoun House showing the stages of c.1706–10. Image: Campbell 1717–25: II, pl. 75

sumptuously furnished' (Campbell 1715–25: II.4). Scholars generally acknowledge the specificity and meticulousness of Campbell's drawings (O'Hara 2010: 114–36), and through James Smith (c.1645–1731), Campbell formed part of Bruce's extended network through which he could familiarise himself with Hopetoun's design (Colvin 1974: 6, 8; O'Hara 2010: 93). Its biaxial symmetry and early manifestation of the type make it a pivotal sample to understand rotunda types in Scotland.

The grid of Bruce's design (Fig. 9) lacks the geometric clarity and perfection found in the designs of Palladio and Serlio. Nonetheless, Bruce designed a central square with two large rooms adjacent to it while the rest of the plan demonstrates a high degree of biaxiality. The asymmetry of the plan results from the addition of two different stairs around the octagonal centre, which stems more from Serlio than Palladio (Macaulay 1987: 21; Howard 1995b: 56). Likewise, one corner accommodates the great dining room rather than being divided into an apartment. By locating two of the four apartments in the flanking ranges rather than the front of the corps-de-logis (the main body of the design), Bruce deviates from Serlio's plans but makes room for more so-called state functions such as dining rooms, a parlour and withdrawing rooms. The inner spatial sequence is defined by a central vista that runs from the hall through the octagonal staircase to the garden parlour opening onto a view of the gardens. The other corner functions have off-centred doors creating *enfilade* rooms to the sides, typical for Baroque houses, but which can also be traced back to Serlio's designs (Serlio New York; Serlio, 1575; Howard 1995b: 59). Hence, the spatial sequence of Hopetoun resonates better with Serlio's royal house rather than Palladio's Villa Rotonda. Bruce's choice of the *enfilade* seems to take in account privacy and functionality since a centrally positioned inner

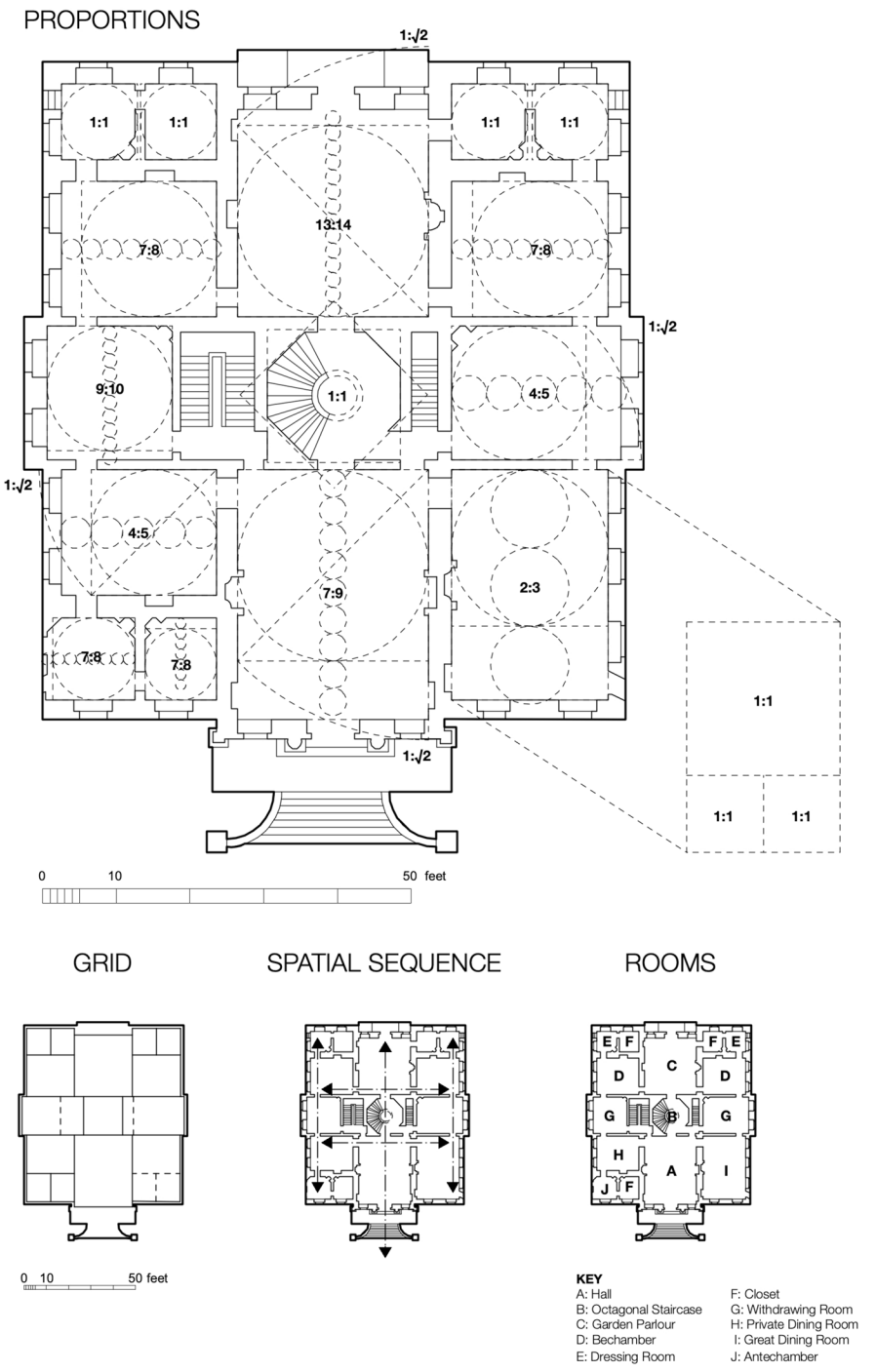

Fig. 9 Analysis of Bruce's Hopetoun House showing the corps-de-logis but not the flanking wings. Image: author

vista would not have complicated its layout due to the off-centred arrangement of most fireplaces. Even more convincing, it appears that Bruce did not place the doors in the middle of the walls due to the paired arrangement of the square closets at the back, resulting in an irreconcilable ending of the vista on a blank wall rather than to a window.

The room ratios at Hopetoun also appear more Serlian than Palladian (Table 4). This becomes evident in the 4:5 ratio of the large withdrawing room as well as in the private dining room, a ratio not recommended by Palladio (Palladio 1570: I.52). Moreover, the dressing rooms and closets all seem to approximate a square proportion. The great dining room adheres to a 2:3 ratio that could stem from both Serlio and Palladio. When drawing up the plan for Hopetoun house in *Vitruvius Britannicus*, Colen Campbell added the measurements of the rooms, and the two bedchambers, as well as the private dining room, which all have different measures and lead to different room ratios (Campbell 1717–25: II, pl. 75). As a result, the private dining room approximates a 4:5 (0.8000) ratio with its decimal notation (0.8095), whereas the bedchambers correspond to a 7:8 ratio (0.9048 versus 0.8750), despite deriving from the same grid division. However, the plan indicates the intent of symmetrical and similar ratios. The dimension of the great dining hall (2:3) allows itself to be divided into an apartment with one bedchamber, a square dressing room (1:1), and a square closet (1:1) mimicking the other lodgings. Similar apartments trace to French examples such as du Cerceau and could have acted as Bruce's inspiration (Rosenfeld 1978: 69; Campbell 2015: 67). In addition, the first-floor apartments of Serlio's royal house closely relate to Hopetoun's arrangement as seen in the large room and two square rooms located at the front (cf. Figure 5). The 2:3 proportion lends itself well to subtracting or adding smaller rooms of 1:1 depending on the need of the building. Yet, when adding wall thicknesses, the schematic division of the clear triple 1:1 or singular 2:3 division deviates into two small rooms approximating the 1:1 proportion and one room tending to either 4:5

Table 4 Approximation error of Hopetoun House with theoretical ratios

Real measure (ft)	Decimal value	Theoretical ratio	Decimal value	Approximation error
10×10	1.0000	1:1	1.0000	0.00%
17×18	0.9444	9:10	0.9000	4.70%
26×34	0.7647	7:9	0.7778	1.71%
26×28	0.9286	13:14	0.9286	0.00%
21×31	0.6774	2:3	0.6667	1.58%
19×21	0.9048	7:8	0.8750	3.29%
19×23	0.8261	4:5	0.8000	3.16%
17×21[a]	0.8095	4:5	0.8000	1.17%
18×18[a]	1.0000	1:1	1.0000	0.00%
11×12[a]	0.9167	7:8	0.8750	4.55%
10×11[a]	0.9091	7:8	0.8750	3.75%
				2.17 mean %

[a]Measured in CAD

or 7:8. This principle results in an elongated rather than square corps-de-logis even though it originates from the square.

Beyond the apartments and withdrawing rooms, the 13:14 ratio of the parlour and the 7:9 ratio of the hall deviate from the seven ratios recommended by Serlio and Palladio. Just as in the case of the apartments the hall's ratio (7:9 = 0.777) approximates 3:4 (0.7500) with a 3.47% error. The divergence of the presupposed 3:4 ratio stems from adding wall thicknesses but equally comes from another implemented proportion which we can perceive in the middle rooms of the four exterior façades which progress slightly outwards. By drawing a square from the inner measurement and projecting the diagonal outwards, a $1:\sqrt{2}$ ratio comes forth, and seemingly determines where the wall progression should end on all four facades. Likewise, the diagonal ratio appears on all four sides with different measures for each underlying room and accentuates a preconceived application of the $1:\sqrt{2}$ ratio. Hopetoun House strongly relates to the designs of Serlio's and Palladio's rotundas. Furthermore, when taking into account the design of the architectural perimeter according to applied ratios, as well as those of the rooms, a proportional harmony results. In his design, William Bruce incorporated several overlapping ratios emulating Serlian rather than Palladian ratios. Nevertheless, Bruce's curved flanks which link the main house to the offices, derive from Palladio's villas even though the corps-de-logis derives from Serlio, whether through the examples of Marot, Marly, or Serlio's manuscript directly (Stewart 2016: 34, 216–17, 304).

Lord Burlington's Chiswick House

Due to the prominence of Lord Burlington in instigating the neo-Palladian fashion as a designer and patron of the arts (Colvin 1995: 128–32), his house at Chiswick forms the quintessential example to compare the architectural ratios of Serlio and Palladio, and remained unexplored until now. Lord Burlington designed Chiswick House himself with the aid of Kent (Fig. 10), collating models of Palladio with references to Jones and Scamozzi (Ackerman 1966: 80, 136; Summerson 1986: 129, 165; Mowl 2006: 55). As a hallmark of British Palladianism, Chiswick House has long been related to Palladio's Villa Rotonda (Summerson 1953, 311; Tavernor 1991, 165), but equally to Serlio's motives (Sicca 1982, 43, 46; Laird 1999, 224; Worsley 2006, 129–30). Giles Worsley (2006: 130) related Serlio's design of a royal house to Chiswick, particularly for its octagonal shape, while Marco Rosci (1966: 37) noted that the octagonal hall with flanking spiral staircases resembles Serlio's plan of the Odeo Cornaro and his royal house (cf. Fig. 5). Recent proof indicates the presence of Serlio's manuscript of the *Sesto libro* in Britain around 1700 (Campbell 2022: 6) and necessitates a revision of the British rotunda type based on Serlio's drawings. It seems inconceivable that Serlio's manuscript was not widely used as its owner Francis Bird (1667–1731) collaborated with Britain's finest architects including Christopher Wren (1632–1723) and James Gibbs (Campbell 2022: 8, 10).

Chiswick House's grid has a square centre, with square rooms on each corner, resembling Serlio more than Palladio, whose drawings Lord Burlington plausibly had engaged with in London (Worsley 2006: 129; Campbell 2022: 10)

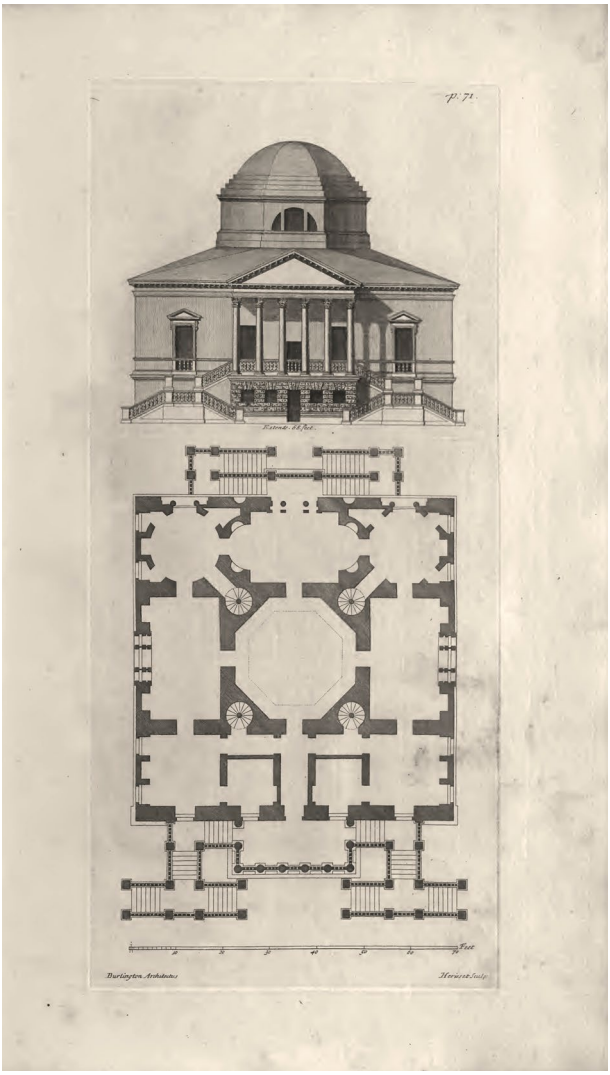

Fig. 10 Plan of Chiswick House. Image: Kent (1727: pl. 71)

(Fig. 11). Beyond Serlio, Burlington could have used du Cerceau's *Troisième livre d'architecture* (1582) or Antoine le Pautre's *Oeuvres d'architecture* (c.1652) as sources for the interior's geometries but not for the overall composition (Rosenfeld 1978: 69). The temple front and ratio of the loggia seemingly stem from Palladio (Tavernor 1991: 77–8). Likewise, the longitudinal entrance with smaller rooms on both sides features the rotundas of the aforementioned designers. Chiswick's other three rooms adjacent to the central hall do not have the same divisions as Palladio and seem rather copied from Serlio's royal house. While the grid exhibits more Serlian than Palladian features, the spatial

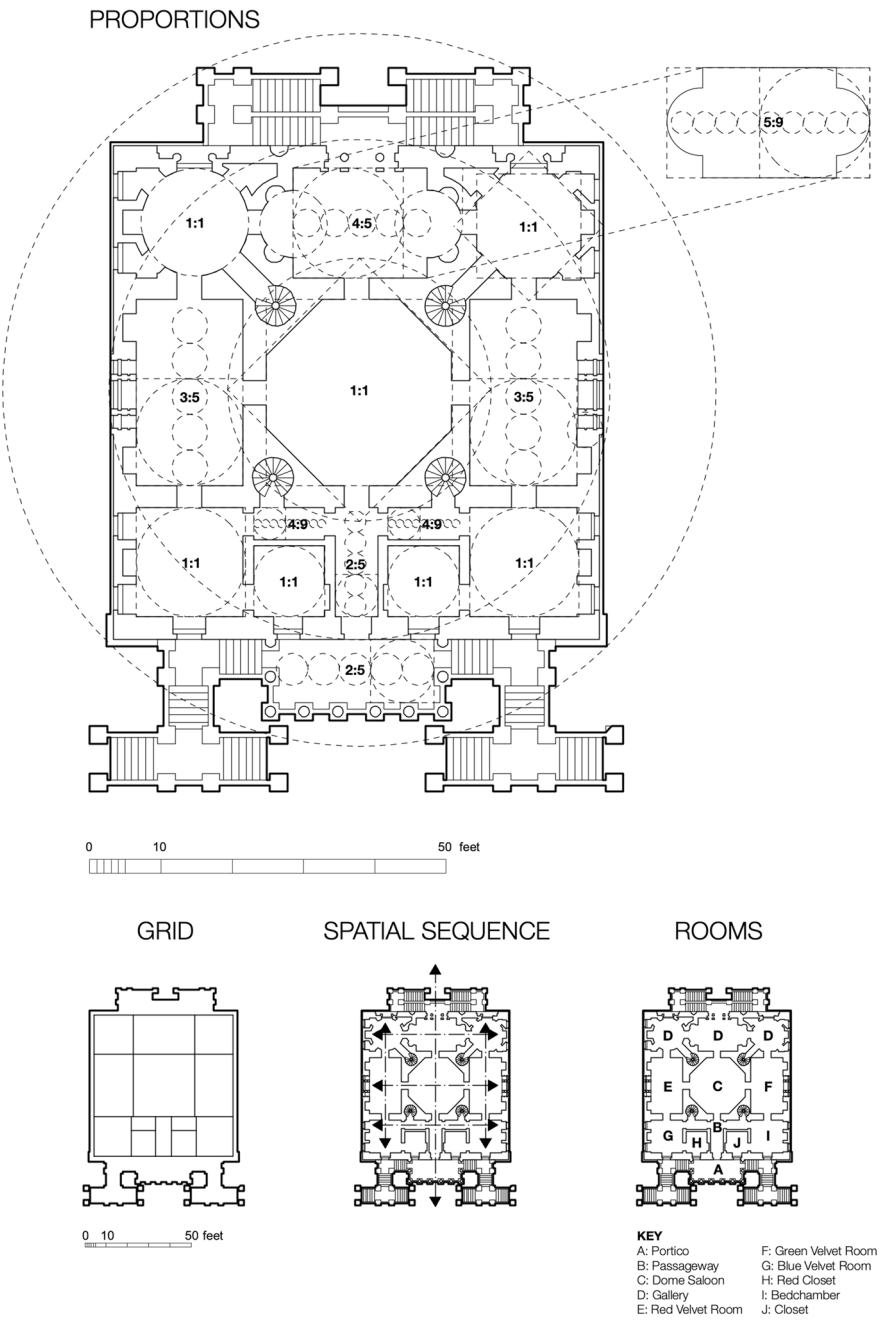

Fig. 11 Analysis of Chiswick House. Image: author

sequences and circulation patterns expose the opposite. The open and transparent plan results from the central position of the doors in the main rooms and contrasts with Serlio's more private spatial sequences. When looking at the room functions, Burlington mimicked Serlio wherein the Green and Red Velvet Rooms act as public rooms similar to Serlio's *salette*. Yet due to Chiswick's more intimate scale, it contains only one bedchamber, meaning Lord Burlington had to retain the pre-existing building to accommodate guests (Harris 1994: 172). Since only Burlington and his wife Dorothy Boyle (1699–1758), Countess of Burlington and Countess of Cork, occupied the house, Palladio's open, transparent spatial sequence did not compromise their privacy.

The most commonly applied ratio remains that of the square (1:1), as seen in all the corner rooms, the octagon and the closets (Table 5) (Hersey 1976: 51; Spallone and Vitali 2019: 296). This implies a closer relationship to Serlio than to Palladio (Serlio 1545: fol. 36; Hersey 1976: 51–55). Moreover, Palladio dismissed the 4:5 in favour of the circle, and, when looking at Burlington's middle Gallery room, with its 4:5 ratio (1.33% error), Serlio's influence seems plausible (Palladio 1570: I.52, 54; Wittkower 1945: 74). When including the apses in the middle gallery, a 5:9 ratio appears, which somewhat approximates a double proportion (0.535; 0.5555 vs 0.5000). In the loggia, Lord Burlington used a 2:5 proportion, a ratio not found in Serlio's nor Palladio's proportional recommendations, but Palladio employs the same ratio in the loggias of his Villa Rotonda. Burlington also comes close to a 3:5 ratio in the Green and Red velvet rooms creating a link between the more public spaces of the house in contrast to the more private spaces. By using these ratios Lord Burlington seemingly mixed Serlian as well as Palladian dispositions and ratios, creating the harmonious composition known as Chiswick House.

Table 5 Approximation error of Chiswick House with theoretical ratios

Real measure (ft)	Decimal value	Theoretical ratio	Decimal value	Approximation error
9×22	0.4091	2:5	0.4000	2.22%
15×15	1.0000	1:1	1.0000	0.00%
15×26	0.5769	3:5	0.6000	4.00%
26×26	1.0000	1:1	1.0000	0.00%
15×19	0.7895	4:5	0.8000	1.33%
15×28[a]	0.5357	5:9	0.5555	3.70%
10×10[a]	1.0000	1:1	1.0000	0.00%
6×15[a]	0.4000	2:5	0.4000	0.00%
4.5×10[a]	0.4500	4:9	0.4444	1.24% 1.39 mean %

[a]Measured in CAD

Conclusion

Looking into the legacy of Serlio's royal house and Palladio's Villa Rotonda in Britain through the cases of Hopetoun House and Chiswick House sheds new light on their genesis. The reading of applied room ratios establishes that the British rotunda forms a distinct plan derived from Serlio as much as from Palladio, overriding what up until now most scholars have unjustly classified as only Palladian. By scrutinising the room ratios of Serlio and Palladio, we can establish the crucial role the architectural ratio played in the development of the British rotunda.

Investigating biaxial symmetries and grid plans reveals the influence of Serlian domestic typologies on early modern British architecture and revisit the image of Palladian authority. Previous scholarship has already connected Serlio's designs to British plans stylistically, but these studies do not provide the same insight as a proportional inspection of their spatial hierarchies. By rereading the ratios in rotunda typologies, we can revalidate the historical position of Serlio and Palladio and their respective influence on British architecture. Both Chiswick and Hopetoun emulate and combine Palladio's and Serlio's models while simultaneously creating novel arrangements which stood at the forefront of architectural design in their respective periods. By revising the Palladian houses in a Serlian way, the genius of Lord Burlington and Bruce led to the reinvention of the rotunda. These examples, however obscure in proportional inquiries, allow us to consider these designs as ingenious examples of early modern mathematical thinking. Presumably, British architects relied on architectural models beyond Serlio and Palladio and made use of more architectural ratios than this present inquiry could cover, laying the foundation for future investigations.

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