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Envisioning the Architectural-Urban Nexus in Renaissance Florence in the Case of Palazzo Rucellai

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Abstract
Florence counts as one of the cradles of European Renaissance art and architecture where linear perspective first emerged. These developments led to the pivotal role perception played in Florence's architectural and urban design conceptions, as seen in the works of Brunelleschi (1377–1446), Michelozzo (1396–1472), and Alberti (1404–1472), among others. Alberti's *De re aedificatoria* presented an analogy of the city as a house and vice versa, negating hard distinctions between architectural and urban design, while Alberti's oeuvre, particularly *De pictura*, underscores the primacy of the eye. This suggests the exploration of mathematical relationships between architectural façades and urban space configurations within the Florentine context. Through this approach, the paper explores the cases of Palazzo Pitti, Strozzi, and Rucellai, and advances ongoing debates regarding Palazzo Rucellai's envisioned finished appearance by using a 3D Digital Twin (DT) of the palace and its immediate urban context to test alternative façade hypotheses. Ultimately, the results unveil the multidimensional character of Renaissance architectural façade design and their urban role as signifiers of the cultural, intellectual, economic, and political valour of their inhabitants.

Keywords Spatial configuration · Leon Battista Alberti · Design composition · Renaissance Florence · Space Syntax · Urban history · Architectural history

Introduction

The Italian Quattrocento brought a new impetus to architecture through humanist philosophy, artistic invention, and technological innovation. Humanism thrived in Rome and Florence with Rome emphasising antiquarian investigation and

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Florence leaning towards unconfined artistic experimentation, including the flourishing of the *all'antica* style that Giorgio Vasari (1511–1574) would later name the *rinascita*—the Renaissance (Vasari 1550: 118). As a result, Florence became one of the leading cultural and intellectual centres of the early modern period, hosting prominent personalities such as Niccolò Machiavelli (1469–1527), Sandro Botticelli (d.1510), and Michelangelo (1475–1564). This firmly ingrained the city into the fabric of western thought, leaving a long-lasting imprint on architecture. In Florence, artists and polymaths like Filippo Brunelleschi (1377–1446), Leon Battista Alberti (1404–1472), and Piero della Francesca (c.1415–1492) developed linear perspective (Wood 2019: 324; Pearson 2022), defined as the visual relationship between the object perceived and the eye of the beholder through 'visual rays' (Alberti 2004: 40). During this time, visual perception influenced the creation and production of art and space as an act of envisioning and soon influenced visual culture across Europe (Kemp 2006: 28–30; Mols 2019). This notion remained alive within art theory, influencing gestalt psychology and its mapping of complex patterns and relationships between perceived forms or images (Gombrich 1972: 24). Thus, through a mathematical and historical reading, this paper scrutinises the visual relationship between architectural façades and urban space configurations in Quattrocento Florentine palazzi, with a focus on the case of Palazzo Rucellai.

Within Florence's urban life, prominent citizens blazoned their wealth by instigating building projects (Trachtenberg 1997; Grafton 2001: 8; Pearson 2011). Here the Florentine palazzi façades formed the main means to express the wealth, magnanimity and magnificence of their owners (Payne 1999:74; Grafton 2001: 8). Among these is Palazzo Rucellai (1446–1460), built by the prominent merchant and patron Giovanni Rucellai (1403–1481). Often regarded as the earliest classicised façade with superimposed orders, it forms a compelling case to explore the visuospatial perception of Florence's townscape (Grafton 2001: 182). Its unfinished façade formed the object of many prior studies that formulated hypotheses regarding its finished appearance. Nevertheless, most studies overlooked its urban context, arriving at an impasse in the academic debate (Hersey 1976; Kent et al. 1981). Considering that testing hypotheses 'is eminently applicable to the story of visual discoveries in art' as explored through schemata and corrections (Gombrich 1972: 272), this paper re-ignites this longstanding debate. This examination places hypothetical formulations at the centre of a novel visuospatial and perceptive study grounded in the foundational works of Benedikt (1979), Hillier and Hanson (1984). By projecting lines of sight to Palazzi façades through a Visibility Graph Analysis (VGA) (Turner et al. 2001), the study mathematically maps visual perception to confound proportional relations of the Palazzo Rucellai and its urban square, as well as urban configurational variations. Such an approach brings the historic reading into the digital realm. This also shifts the focus from the design of its façade, as an isolated object, and considers its role in defining a positive urban space, coalescing to the context of Renaissance Florence, Palazzo Rucellai, and Alberti's writings. Where historical sources seize to offer new evidence, and configurational analyses fail to provide contextual interpretations, their combination provides a robust

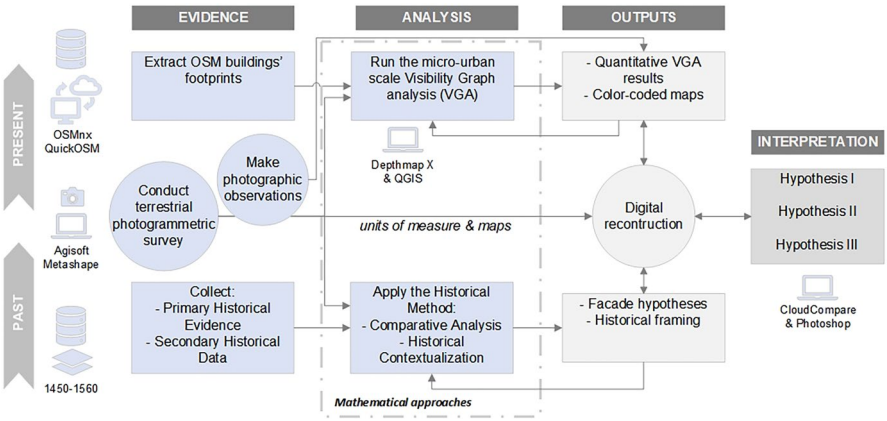

Fig. 1 Research design and workflow diagram

response and sheds a new light on the debate regarding the architectural-urban nexus in Renaissance Florence (Mols and Pezzica 2023).[1]

Ultimately, the visuospatial relationship between the architectural façade and the urban realm stands at the core of this study. First, the paper maps the prominent Quattrocento palazzi of Florence to discern this type of correlations. Next, through a VGA analysis, it compares visuospatial features of Palazzi façades and their urban squares, using the examples of Palazzo Pitti (1457–1470), Palazzo Strozzi (1489–1534), and Palazzo Rucellai. As a more in-depth case, the paper then probes Palazzo Rucellai's design, adding to the enduring debate regarding its envisioned finished appearance. To this end, the study juxtaposes a Digital Twin (DT) survey of Palazzo Rucellai to the VGA and a reading of Alberti's *De pictura* (Alberti 1435, 2004), *Della tranquilità dell'animo* (Alberti Palatino ms), and *De re aedificatoria* (Alberti 1485, 1988), while considering Giovanni Rucellai's *Zibaldone quaresimale* (c.1457) (Perosa 1960; Kent et al. 1981). Furthermore, the research recapitulates a long-held debate regarding Rucellai's envisioned façade that had only recently been reinstated, calling for further exploration (Mols and Pezzica 2023). Finally, the combined reading of history alongside urban modelling stipulates new insight that invite new hypotheses. In turn, these hypotheses better accentuate the importance of Florentine Palazzi as artistic, political and economic devices that enforce carefully engineered spatial hierarchies and integrally interrelate into Florence's urban fabric.

[1] For the prior DT see: https://www.youtube.com/watch?v=y1jnoqzB5Lw.

Methodology

To reinstitute the visuospatial relationship of Palazzo Rucellai and its urban environment, the paper adopts a mixed-method study that combines approaches from architectural history, urban studies and digital documentation (Fig. 1). For further contextualising Palazzo Rucellai within the Florentine context, the cases of Palazzo Pitti and Strozzi are considered alongside Rucellai. Data used in this comparative study include city-scale historical resources, OSM building footprints, and supplementary historical data for Palazzo Rucellai and Pitti to reconstruct its Quattrocento spatial configuration. Further, a low-cost DT model of Palazzo Rucellai, including its loggia and square, is generated to impose a historical and configurational analysis to test alternative façade hypotheses. The latter also deploys Virtual Reality (VR)[2] visualisations in relation to the DT reconstruction for testing the envisioned hypothesis and their perception from the middle of Piazza de' Rucellai.

Case Study Selection

Palazzo Rucellai, as an early progenitor of the *all'antica*, forms the ideal case to scrutinise the visuospatial connection between architecture and Florence's cityscape. Palazzo Rucellai is widely known for its unfinished façade of seven pilastrated bays with Doric and superimposed Corinthian orders. Together with its *opus reticulatum* plinth, and *stiacciato* masonry-effect, it presents a markedly unique architectural composition. This sparked wide scholarly interest, as seen in the drawings and descriptions of early historians as Montigny, von Geymüller, and von Schlosser (Montigny and Famin 1806; von Stegmann and von Geymüller 1885–1907; von Schlosser 1924). Likewise, a plethora of studies investigated the symbolism and iconography of Palazzo Rucellai, its owner, and its façade (Kent et al. 1981; Samperi 2005; Bulgarelli 2006; Gurrieri 2009; Gaborit 2013). While mostly inconclusive, proportional studies exist, which extensively surveyed or elaborated on Palazzo Rucellai's composition (Naredi-Rainer 1982: 168–72; Frommel 2006: 345; Feola 2006). Likewise, the debate regarding its façade hypotheses traces back to the mid-late twentieth century, stipulating an original design of 5-bays (Sanpaolesi 1963), negotiating or proposing an 8-bay façade (Mack 1974; Saalman 1988; Rykwert and Engel 1994; Ragazzo 1994), remaining undecided on the 8-bay or 9-bay hypotheses (Kent et al. 1981), or deciding on an 11-bay or even 14-bay façade (Hersey 1976). Only recently, new studies have unveiled potential for revisiting the façade hypotheses using a micro-scale urban DT and VR, arguing against formulating new hypotheses (Mols and Pezzica 2023). However, these studies did not situate the façade hypotheses within Florence's broader historic urban context. Likewise, they did not test their accuracy or approximation error based on plot boundaries. While addressing such a gap, this paper posits plausible hypotheses of 8, 9 and 11-bay

[2] For the VR walkthrough see: https://www.youtube.com/watch?v=dwUleJYZYC8.

Fig. 2 DT of Palazzo Rucellai's façade, square, and loggia

façades of the envisioned urban appearance of Palazzo Rucellai, by reading the palazzo's architecture in relation to the wider urban fabric through a VGA (Fig. 2).

Digital Workflow

Overall, the conjoint historic-spatial reading and multidomain study of the façade hypotheses relied on a sequential digital workflow (cf Fig. 1). First, the rapid photogrammetric survey of Palazzo Rucellai that took place in 2022 collated 33 high-resolution spherical images (6080 × 3040 pixels). The use of 360º cameras yields greater affordability than Terrestrial Laser Scanning (TLS), better befitting this study. Next, a photo-realistic DT of Palazzo Rucellai was created (via Sfm-MVS) in Agisoft Metashape as a basis for testing the visuospatial relationships of Palazzo Rucellai's façade hypotheses. For historical accuracy, the DT model was extracted and scaled according to the Florentine *braccio* (58.3 cm) (Naredi-Rainer 1982: 168). This measure was chosen due to its prominence within proportional studies despite minor diverging metric measurements for the Florentine *braccio* exist (58.6 cm) (Frommel 2006). The resulting scale correlates with Alberti's practice of using the *braccio* as the module for developing perspective and architecture, forming the main building block for his own designs (Alberti 2004: 54; Kemp 2006: 28). Next, the 2D spatial configuration of Palazzo Rucellai—as well as of Palazzo Strozzi and Pitti—was analysed using a VGA. While borrowing from Benedikt's isovist to mathematically represent a field of view, in line with Space Syntax theory, the VGA proposes a quantitative analytical conceptualization of space to explore its potential correlation with human behaviour. This is accomplished by revealing spatial visibility and/or permeability relationships within a graph built from the vertexes of a 2-dimensional grid of cells imposed on the environment in front of the Palazzo. As such, besides capturing local visibility properties associated to the isovist or the graph, the VGA also maps broader accessibility and connectivity patterns of the square's spatial configuration. For consistency, the VGA lattice

Table 1 Mapping of 19 Florentine palazzi, considering the bays of the main façade in the Ground Floor (GF) and 1st Floor (F1), and all major openings

Palazzo name	Year	Architect	Bays GF	Bays F1
Palazzo Spini-Feroni	c.1289	Lapo Tedesco, Arnolfo di Lapo (attr.)	9	13
Palazzo Castellani	mid-14th c	s.n	5	5
Palazzo Davanzati	c.1350	s.n	3	5
Palazzo Bardi	1410	Filippo Brunelleschi (attr.)	6	8
Palazzo Lenzi-Quaratesi	c.1430–1470	Michelozzo (attr.)	5	9
Palazzo Barbolani di Montauto	1444–1446	Leon Battista Alberti (attr.)	3	8
Palazzo Medici-Ricardi (phase 1)	1444–1469	Michelozzo	8	10
Palazzo Rucellai	1446–1460	Leon Battista Alberti, Bernardo Rossellino (attr.)	7	7
Palazzo dello Strozzino	1451–1469	Michelozzo	6	7
Palazzo Pitti (phase 1)	1457–1470	Luca Fancelli	7	7
Palazzo Pazzi	1458–1469	Giuliano da Maiano	5	9
Palazzo Antinori	1461–1466	Giuliano da Maiano	4	6
Palazzo della Gherardesca	1472–1490	Giuliano da Sangallo	7	7
Palazzo Horne	1480–1490	Giuliano da Sangallo, Simone del Pollaiolo (attr.)	4	4
Palazzo Strozzi	1489–1534	Giuliano da Sangallo, Simone del Pollaiolo (attr.)	9	9
Palazzo Gondi	1490–1501	Giuliano da Sangallo	7	7
Palazzo Albizi	c.1500	Baccio d'Agnolo, Simone del Pollaiolo (attr.)	13	9
Palazzo Panciatichi-Ximenes	c.1500	Giuliano da Sangallo, Antonio da Sangollo the elder, et al	5	5
Palazzo Corsini-Serristori	c.1500	Baccio d'Agnolo	8	8

grids' resolution was set to 1 Florentine *braccio*, which roughly corresponds to the space occupied by a human in plan. Hence, both the VGA and DT correlate to the Florentine *braccio*, but numeric calculations in Tables 1, 2, 3 and 4 are highlighted in metric units for enhanced readability.

Quattrocento Palazzi in Florence

An in-depth analysis of Palazzo Rucellai requires understanding the Florentine style and its context, as well as aligning Albertian theory to the study of the palace design. The exact building dates of Palazzo Rucellai are uncertain, and heavily debated, but are generally ascribed to the dates between 1446 and 1451 by Renaissance authorities or c.1446 to the 1460 s more recently (Kent et al. 1981; Saalman 1988). Moreover, Alberti's involvement in the design of Palazzo Rucellai's façade remains speculative, but his collaboration and connection with Giovanni Rucellai is well known around the time of Palazzo Rucellai's construction (1446–1460 s). As such, we can assume that Giovanni, a fervent humanist, took inspiration from, or even actively implemented, Alberti's theories in the construction of his palazzo. At this time, Alberti was still writing his seminal *De re aedificatoria libri decem* but already completed *De Pictura* and *Della tranquillità dell'animo*, which provide a key insight into the conception of the Palazzo Rucellai and surrounding environs. Particularly, Alberti's characterization of the dwelling as a small city is noteworthy. He emphasises this notion when mentioning that 'with the construction of the house, […] almost everything relevant to the establishment of a city must be taken into account' (Alberti 1485: V.14; Alberti 1988: 140). Moreover, Alberti highlighted that 'we judge by sight,' placing emphasis on the perception of the visuospatial relationship of the façade and the square (Alberti 2004: 40). Notably, Giovanni actively sought to extend his Palazzo to exemplify his rising status as a prominent Florentine citizen. Since he purchased and demolished the houses in front of his palace across Via della Vigna Nuova to make room for a square, we can assert with some certainty that Giovanni placed major emphasis on the visuospatial relationship between the square and his Palace façade. Nevertheless, further explorations are required through methods such as mapping, to discern such an architectural-urban nexus within the Florentine context of the Quattrocento.

During the Quattrocento, the mediaeval spirit of Firenze interluded into the *all'antica* style where many of its torri made way for the palace type. Yet, the shift to façades with odd bays, often associated with the classical style, emerged in a gradual and piecemeal fashion (Goy 2002: 9). From the nineteen major palazzi that were built up to 1500, thirteen (68.4%) contain irregular bays in their main façade, on the ground floor and piano nobile (Table 1). Hence, while regular bays formed an important part of Florentine architecture (31.6% of palazzi), the prevalent tradition built according to irregular bays, providing knowledge to contrast the façade hypotheses in the later part of the research.

When geographically mapping this information by considering the presence, or absence, of a square in front of the façade, a spatial hierarchy emerges (Fig. 3).

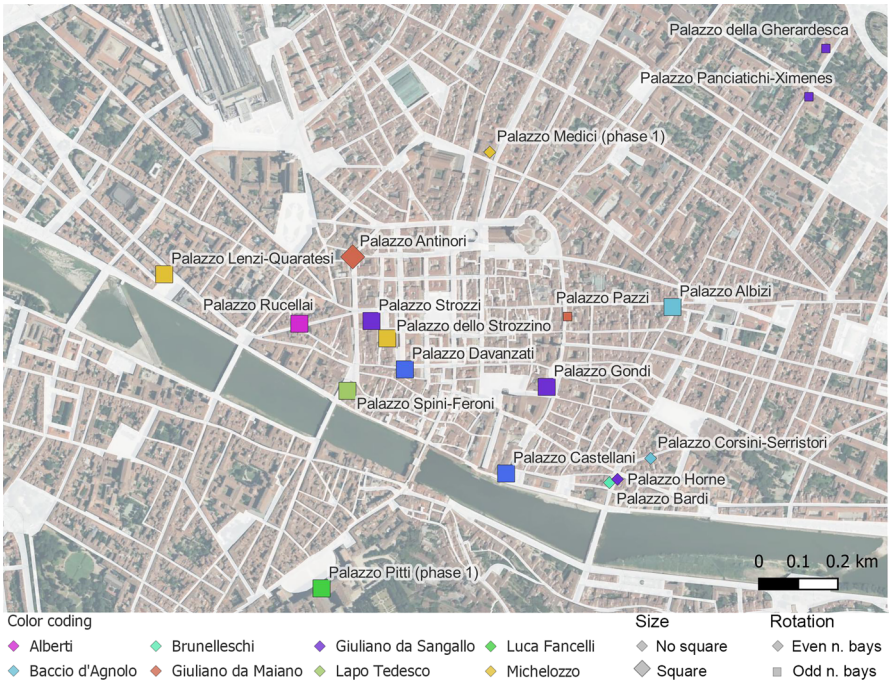

Fig. 3 GIS Map of 19 Florentine palazzi showing the architect, and attributes of bays and squares

Eleven palazzi, or ~ 58%, lie in front of a square, whereas the remaining 42% align to a regular street. Yet, the map clearly shows a higher density of palazzi beside a square around Florence's historic city centre, whereas street-alignments prevail towards the periphery, where the availability of bigger plots and gardens diminished the need for large urban spaces. Prior scholarship alluded to this spatial arrangement as a ring of palazzi around the historic nucleus (Goy 2002: 60). This mapping indicates that the visuospatial relationship between urban squares and Florentine Quattrocento palazzi was indeed significant, confirming the relevance of a revisited analysis of Palazzo Rucellai.

Square-Façade Relationships in Palazzo Pitti, Strozzi, and Rucellai

Palazzo Rucellai, forms the ideal case to scrutinise the visuospatial connection between architecture and Florence's cityscape. Nevertheless, to support the claim on the interrelated architectural-urban relationship, we first examine the three most famous examples of Florence's Palazzi, namely Palazzo Medici-Riccardi, Palazzo Pitti, and Palazzo Strozzi (Mack 1974; 517; Goy 2002: 257). Cosimo de' Medici commissioned Michelozzo to build the Palazzo Medici-Riccardi (1444). Palazzo Medici is an early case of Renaissance palazzi built by the powerful Medici, the *de*

Fig. 4 Lunette painting of Palazzo Pitti, Fort Belveder and Boboli gardens Giusto Utens, 1599, Tempera on panel. Image: Museo di Firenze com'era

facto rulers of Florence, that influenced later Florentine architectural developments (Grafton 2001: 325; Goy 2002: 257–59). In 1457, Luca Pitti constructed Palazzo Pitti, plausibly designed by Luca Fancelli despite its historical attribution to Brunelleschi. While competing in size with Palazzo Medici, only seven bays were initially completed, before becoming one of Europe's vastest and exalting ducal courts when the Medici purchased the palazzo (Goy 2002: 9). Palazzo Strozzi, as the last example of the grand Florentine Quattrocento palazzi, was built from 1489 onwards by Filippo Strozzi according to the designs of Sangallo, and is often regarded as the culmination of the matured Florentine Renaissance palazzo architecture (Goy 2002: 264, 266). Of these, Palazzo Pitti and Strozzi allow for the testing of their visuospatial relationships through a VGA in parallel with Palazzo Rucellai, while Palazzo Medici is excluded as it does not lie near a prominent urban square.

The VGA is initiated by considering the historic condition of Quattrocento Florence. While existing OSM data works well in the case of Palazzo Strozzi, the other cases require modifications to take the historic context of Palazzo Rucellai and Palazzo Pitti into account. Today, Palazzo Pitti presents a 23-bay façade in front of its square, which diverges from the original 7-bay configuration during the Quattrocento. Giustio Utens painted Palazzo Pitti around 1599, and still shows the original 7-bay façade and adjacent door that breaks the seemingly symmetrical relationship of the square and palazzo (Fig. 4). Based on a combined reading of Giusto Utens' lunette painting that shows the urban contour of the square with the Montigny-Favin survey of Palazzo Pitti (Fig. 5) (Montigny and Favin 1806: pl.3) the width of the original façade and square is determined and plotted on top of OSM data in CAD. The reconstruction copies the contour of the superimposed street boundary, completing the building block around Palazzo Pitti. This reconstruction

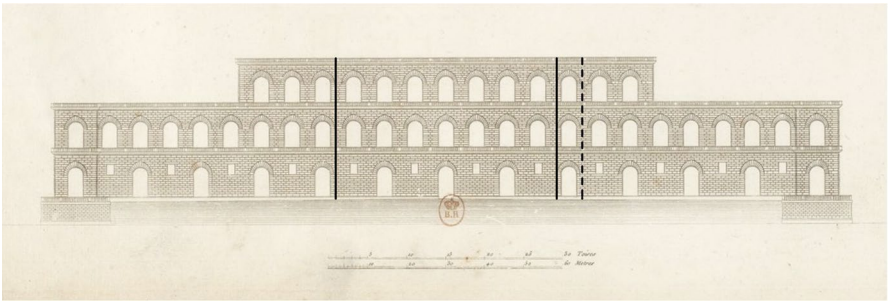

Fig. 5 Palazzo Pitti with highlights of the original 7-bay façade. Image: Grandjean and Favin 1806, pl 3

Fig. 6 Definition of the configurational analysis' boundaries for Palazzo Rucellai, Strozzi, and Pitti and 1 *braccio square grid overlay (light blue)*

bases itself on the Buonsignori map of Florence (1584) as it provides more detail than the earlier Rosselli map (c.1470) that equally depicted the 7-bay Palazzo Pitti. For Palazzo Rucellai, the OSM data geographically locates and aligns the DT in GIS, following an initial rough scaling based on in situ measurements. Based on the different dimensions of each palazzo, the respective radius of 60, 80, and 100 *braccia* is drawn from the centre of each square to determine the boundary of the VGA, before overlaying the analysis grid to the space and generating the visibility graph (Fig. 6).

Of the 25 VGA metrics that can be calculated using DepthmapX (Varoudis, n.d.; Koutsolampros et al. 2019), this research presents a comparative view of a smaller and meaningful selection over the three selected cases (Fig. 7). These comprise: (i) *Isovist Area* (local, geometric); *Visual Clustering Coefficient* (local, topologic), *Visual Control* (semi-global, topologic) and *Through Vision* (local, topologic). Global VGA metrics were excluded from this study due to their poor significance and relevance within the scope of the presented research.

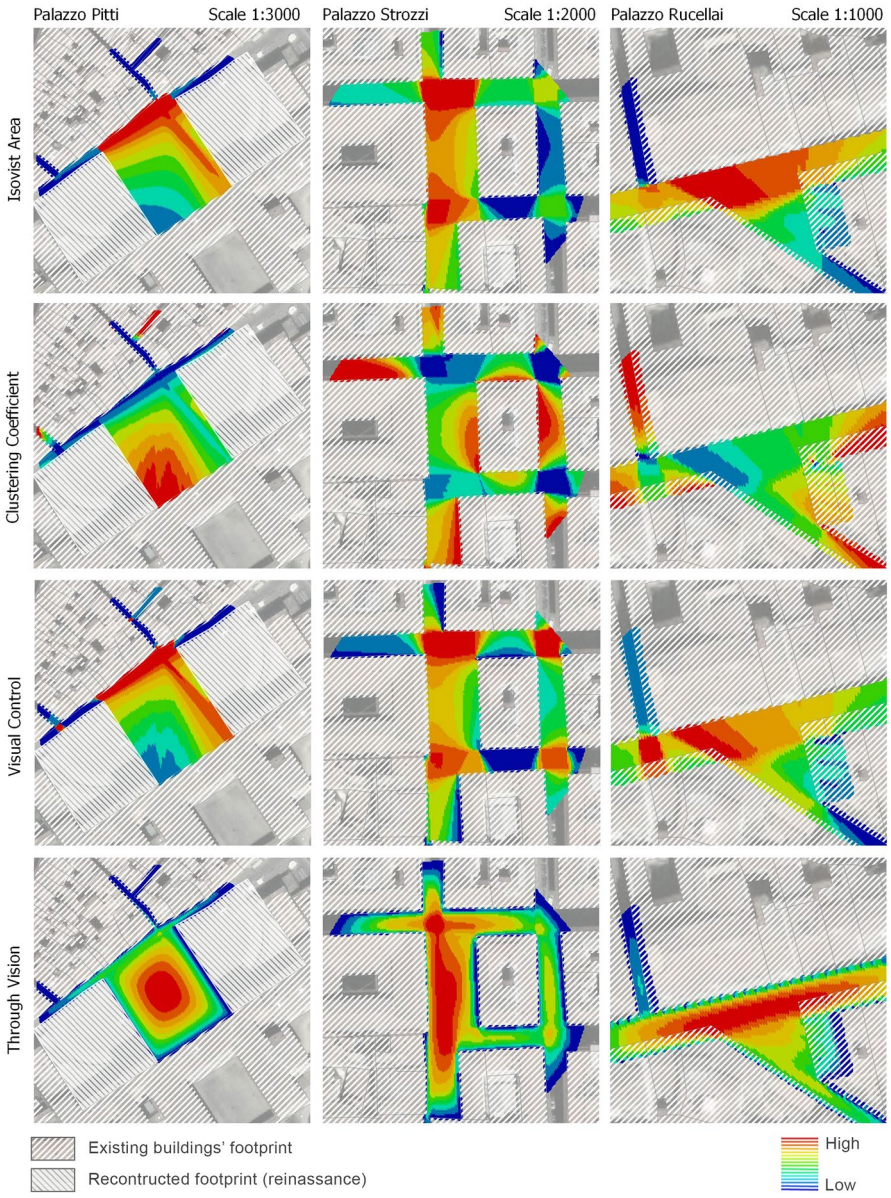

Fig. 7 Comparative VGA of Palazzo Pitti, Strozzi, and Rucellai, showing *Isovist Area*, *Visual Control*, *Visual Clustering Coefficien*t, and *Through Vision* values' distribution

The *Isovist Area* metric was selected for its semantic clarity and in lieu of *Connectivity*[3] (also known as Degree Centrality) as the two output maps resemble

[3] Measures the amount of cells visible from a specific vertex.

one another, due to the small grid size adopted in this study. For Palazzo Pitti, as expected, the *Isovist Area* values are low along the transversal streets. The metric registers a steep increase upon entering the square, where a large space opens and the central façade of Palazzo Pitti emerges. Yet, the highest *Isovist Area* values are found not only on the side of the square opposite to the façade, but also along the viewline that extends towards the place from the transversal street (Sdrucciolo de' Pitti), revealing the visual assymmetry of the spatial configuration. In the cases of Palazzo Strozzi and Rucellai the highest *Isovist Area* values are located adjacent to the main façades, along the continuations of Via Monalda and Via dei Pescioni for Strozzi, and Via della Vigna Nuova for Rucellai. In both cases of Strozzi and Rucellai, the primacy of the eye of the beholder places emphasis on the respective façade in accordance with the importance of vision and its connection to the urban realm during the Renaissance (Trachtenberg 1997). Yet, the highest values situate directly in front of the main door in the case of Palazzo Rucellai only.

Similarly, *Visual Control* (Turner 2001: 31.4) enabled highlighting spots providing a comparatively higher visual overview into their neighbouring spaces. While points with higher *Visual Control* values are distributed in a way that is close to *Isovist Area* values, this metric better highlights crossroads, and more generally, spaces where people decide their navigation while walking. In the case of Palazzo Pitti, pedestrians maintain a good overview over the square, perceiving anyone approaching the palace. In the case of Strozzi and Rucellai, the spaces close to the façades are highlighted once more, setting light to the strategic importance of their location to maintain visual control on the surroundings.

The *Visual Clustering Coefficient* (Turner et al. 2001) identifies compact pockets of space characterised by intervisibility properties and suits more static forms of social interaction (Cutini 2003). The analysis here highlights that only the piazza in front of Palazzo Pitti (in its south-west corner facing the second entrance) affords this type of space occupation, while the spaces in front of Palazzo Strozzi and Rucellai orient towards people's movement. Yet, the Rucellai loggia offers a higher opportunity for sustained space inhabitation than any of the other spaces within the square. Unlike Florentine squares like the Piazza della Signoria, Piazza di San Giovanni, or the Mercato Vecchio (or Piazza della Repubblica) with their respective political, religious, and economic urban function, the main goal of the squares in front of these palazzi was to signify the grandeur and significance of their owners (Saalman 1988: 88). Seemingly, prominent Florentines preferred building their residences near squares, inextricably tying the façade of their homes to the city and its urban experience.

Yet, a comparatively different spatial vocation of Piazza de' Pitti, with respect to Piazza de' Rucellai and Piazza degli Strozzi, emerges from the peculiar values' distribution of *Through Vision* (Turner 2007), which highlights the central locations as those having the highest through-movement potential. In the case of Palazzo Pitti, this denotes the centrality of the square, which as consequence places emphasis on the palace. However, this measure approximates movement potential particularly well along straight walking paths, as it happens in the cases of Palazzo Strozzi and Rucellai where the main routes are clearly detected by the analysis. Indeed, a former urban-level configurational analysis (Mols and Pezzica 2023) revealed that Palazzo

Rucellai directly faces a route—the Via della Vigna Nuova—which naturally attracts pedestrian flows, serving as a pathway for individuals crossing the city. This highlights the high spatial attractiveness of the location, which Giovanni Rucellai developed as a hub for his commercial activities. In all cases, the distribution of movement potential not only highlights the urban importance of palace façades, but also indicates the different modalities and preferential observation points from which it is observed. Different from the narrow Florentine urban canyons, their respective squares, allow for light to enter the city, providing a visual treatment to the eye and brisk point of relief, where palace façades form the main agent of the urban theatre.

Beyond analysing each individual metric, the combination and overlapping of different information layers helps comprehend the interplay of urban form and human experience towards reassessing the façade composition of Palazzo Rucellai. The four selected configurational metrics collectively outline the interplay between the palace and the city, as well as the functioning of the square as urban theatre.[4] Designed according to the sense of vision, the square seemingly formed a crucial role in establishing the visuospatial relationship with the palazzi façades. Moreover, the digital maps provide a foundation that facilitates the discussion and testing of the Rucellai façade hypotheses in 3D. The study focused on elements located at eye level, such as entrance doors, while considering the loggia permeable, allowing us to better appreciate the spatial qualities afforded by it, according to the original design intent, in the VGA maps and VR reconstructions.

Envisioning Palazzo Rucellai

The merchant and patron Giovanni Rucellai commenced the building of his house which became known as the first classicised façade since antiquity with its regularised and superimposed orders of pilasters (Onians 1988: 182; Grafton 2001: 182). Beyond the façade, he sequentially enlarged his palace, including the construction of a loggia and square (Perosa 1960; Kent et al. 1981). Rucellai also enriched his public image through numerous other building schemes throughout the city of Florence, by commissioning Alberti with completing the unfinished façade of the Santa Maria Novella (c.1458–70), the Rucellai Sepulchre in the San Pancrazio (1458–1467) and the Villa Rucellai a Quaracchi (c.1459) (Kent et al. 1981; Waldman and Preyer 2010; Rinaldi 2019). These building schemes consolidated Giovanni's image as a wealthy and powerful member of the Florentine urbs, designating him the nickname of *Giovanni delle fabbriche*. Moreover, Alberti associates to all these building projects, showing an important tie between him and Rucellai. While Alberti's involvement in the Palazzo Rucellai remains inconclusive, scholarship attributes its designs to Alberti and the execution to Bernardo Rossellino (1409–64) (Kent et al. 1981; Gurrieri 2009; Gaborit 2013), whereas the building of the loggia is attributed to Antonio di Migliorino Guidotti (s.d.) (Preyer 1977: 194). Beyond

[4] The concept of urban theatre is discussed in Camillo Sitte *Der Städtebau nach seinen künstlerischen Grundsätzen (1889).*

investing in building projects, Giovanni published his *Zibaldone quaresimale* (c.1457), a new type of commonplace book that rose in prominence during the Quattrocento (Perosa 1960; Kent et al. 1981; Welch 1997:127). Both Rucellai's intellectual accounts and edificatory undertakings highlight his rising status, leading him to hold numerous provisional positions in the Florentine *Signoria* between 1463 and 1475 (Kent et al. 1981: 67). Additionally, the *Zibaldone* indicates Rucellai's humanist interests, frequently citing Aristotle and Seneca, and gives insight into the intellectual framework in which the Palazzo Rucellai was conceived.

Giovanni acquired his house in 1428 and started accumulating wealth in the 1440's when he purchased further plots (Mack 1974; Preyer 1977). It is speculated that the original façade was erected around 1451–55, after obtaining the property of the adjacent house, belonging to his mother Caterina Pandolfini (s.d.) (Sanpaolesi 1963; Mack 1974: 522; Frommel 2006: 345). Subsequentially, Palazzo Rucellai was altered and evolved during the 1450's and 60's eventually leading to the current unfinished 7-bay façade with loggia and square. Yet such dating has been challenged, with proponents dating it to the 1460's, on the basis that its façade was perceived too innovative in style, while highlighting a lack of historic evidence regarding Alberti's involvement (Mack 1974). Such assertions, stand in stark contrast with the Renaissance dating of the palazzo's construction to the period 1446–51 (Kent et al. 1981: 179) and equally don't consider Filarete's (1400–1469) observation of Rucellai's *Casa grande* in 1461 (Kent et al. 1981). While Palazzo Rucellai takes a unique position in the development of the palace façade typology, particularly due to the use of pilasters, it remains incorrect to state the façade has no precedence. The deployment of pilastrated façades was well developed in religious edifices, as seen in the interior and upper floor of the Pazzi Chapel (1442–78) in Florence. Likewise, Alberti already implanted similar design approaches in the concurrent Tempio Malatestiano in Rimini (1447–60), and the Santa Maria Novella in Florence (1448–70), and formulated his wall-column theory (Wittkower 1967). But even beyond religious examples, Corinthian pilasters are observed in the Brunelleschi's *salone* of the Palazzo di Parte Guelfa (1420), that shows his typical white–grey style. Roughly contemporary to Rucellai, the *sgraffito* of painted columns found in Palazzo Barbolani di Montauto (1444–1446), and the later Palazzo Lenzi-Quaretesi (c.1470), located at a stone's throw from Palazzo Rucellai, show a similar façade treatment albeit in a more ornate, less classicised, and grotesque manner. Taken these edifices into account, both Giovanni Rucellai and Alberti could have known these examples, and could have translated these ideas into a petrified rather than painted form. As a result, the original 5-bay façade was most likely completed around 1455, with later further alterations.

This leaves us with Giovanni's vision for completing his façade. Envisioned scenarios only remain hypothetical—as no answer can unequivocally prove Giovanni's thoughts. Nevertheless, in the words of Gombrich, art culminates from the making and matching of images where 'confirmations of these hypotheses can never be more than provisional while their refutation will be final' (Gombrich 1972: 24). What remains certain is that the abrupt ending of the façade with its irregular and fractured *stiacciato* blocks, break the symmetry and harmony leading

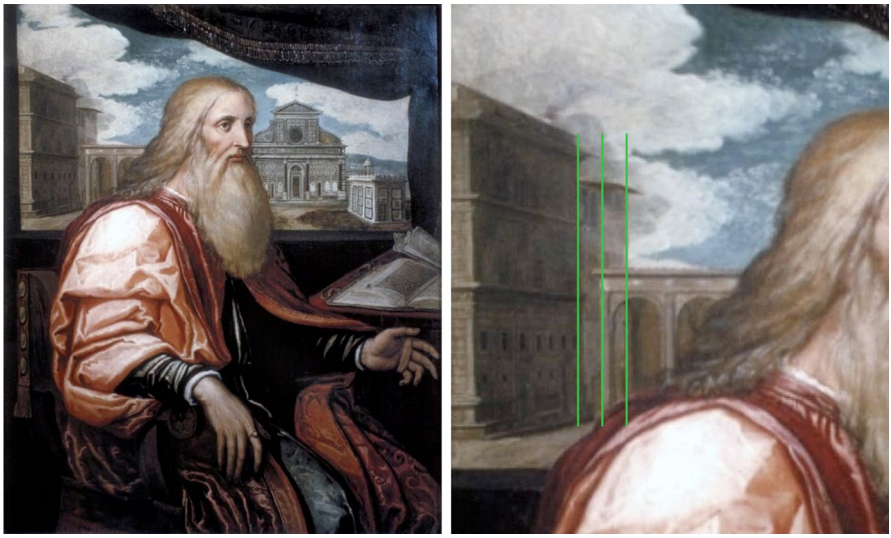

Fig. 8 Left, painting of Giovanni Rucellai, Attr. Francesco Salviati (de Rossi), c.1540. Collezione Rucellai. Oil on panel; Right, zoom on Palazzo Rucellai and its two adjacent plots emphasized

to an indisputably unfinished façade. Sparce evidence does allow for the positioning of reliable approaches to impose hypotheses for the intended façade, however inconclusive such formulations remain. The posthumous painting of Giovanni Rucellai by the painter Francesco Salviati (1510–1563) shows his impression of the Florentine patron (Waldman and Preyer 2010: 134). Intended to highlight the importance of Giovanni for the development of the city, its background shows Giovanni's building projects, including the Palazzo Rucellai and its loggia. When closely examining the composition, Salviati did not only include the 7-bay palace, as it existed by the end of Giovanni's life (Fig. 8). Rather it also includes the two adjacent plots next to the palazzo, which alludes to a 11-bay façade, at least according to a sixteenth century vision. Equally it calls for revisiting the predominant hypotheses regarding its finished façade. These consist of 8-bays or 9-bays by adding one adjacent plot, and 11-bays by adding the two contiguous houses as the Salviati painting indicates.

The DT of Palazzo Rucellai allows for a comparison of physical measurements with plot boundaries derived from OSM data (Fig. 9; Table 2). The edge of the palazzo where the Via della Vigna Nuova and Via dei Palchetti meet is taken as the outer limit, from which the distances of plot lines between the DT model (in green) and OSM data (in blue) are measured to determine the approximation error of the surveys. Determining the exact width of the seventh bay remains challenging due to the whimsical and crotchety façade ending (Sanpaolesi 1963; Kent et al. 1981). Its limit is determined at the point where the ground floor plinth ends, which roughly equates with the ending of the entablatures of the *piano nobile*. The proportional alignment of the DT and OSM data requires discerning its approximation error to establish the DT as falling within acceptable 5% tolerance thresholds in historic

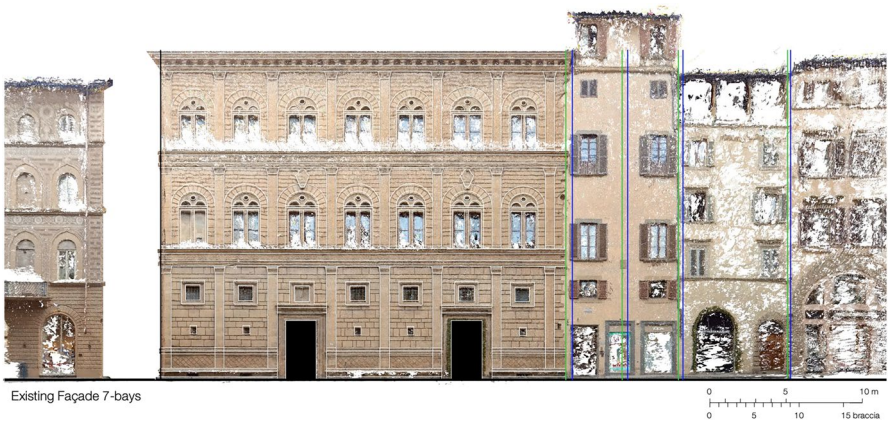

Fig. 9 Façade of Palazzo Rucellai with the DT plot boundary (green) and the OSM plot boundary (blue)

surveying practices (Andrews 2009: 2.1.2). As expected, the DT falls well within this range, and is henceforth used as the measure for imposing and developing the hypotheses for the 3D façade reconstructions.

Pre-existing measurements of the Rucellai façade exist including the 1806 survey of Grandjean and Favin, as well as the Sanpaolesi survey from 1963, among others (Grandjean and Favin 1806; Sanpaolesi 1963). Previously, the 1963 survey formed the basis of proportional inquiries of the façade's geometry (Borsi 1977; Kent et al. 1981; Naredi-Rainer 1982). Yet, the DT offers greater accuracy than the Sanpaolesi survey and provides a more up-to-date 3D digital model. The Sanpaolesi survey did highlight the existing variations of the bays of Palazzo Rucellai, which asserted Sanpaolesi's thesis for a 5-bay origin of the façade, that scholarship broadly endorses (Sanpaolesi 1963; Frommel 2006: 345). Measured from the Rucellai DT, the pilasters and bays' position considered pilaster 1 and bay 1 lying at the south-western end of the façade and gradually moving to bay 7 and pilaster 8 towards the north-eastern side of the façade (Table 3). The pilasters vary in size from 0.580 to 0.670 m which roughly conforms to a Florentine *braccio* (0.583 m) which Alberti used as a design unit for his projects (Naredi-Rainer 1982; Kemp 2006: 28). Likewise, two types of bays are observed. The bays containing windows vary from 2.870 m and 2.920 m, whereas the two bays with doors are the widest with a length of 3.250 m and 3.290 m respectively. Since Giovanni wanted to alter

Table 2 Approximation error of the three hypotheses

	DT measure	OSM measure	Differential measure	Approximation Error
Existing façade: 7-bays	26.560 m	26.987 m	0.427 m	1.58%
Hypothesis 1: 8-Bays	30.250 m	30.611 m	0.361 m	1.18%
Hypothesis 2: 9-Bays	33.940 m	34.234 m	0.294 m	0.86%
Hypothesis 3: 11-Bays	41.100 m	41.298 m	0.198 m	0.48%

Table 3 DT measurement of the bay and pilasters of Pallazzo Rucellai

Architectural element (from left to right)	Measurement (m)
Pilaster 1	0.670
Bay 1 (window)	2.880
Pilaster 2	0.600
Bay 2 (window)	2.870
Pilaster 3	0.610
Bay 3 (door)	3.250
Pilaster 4	0.610
Bay 4 (window)	2.890
Pilaster 5	0.600
Bay 5 (window)	2.870
Pilaster 6	0.570
Bay 6 (door)	3.290
Pilaster 7	0.590
Bay 7 (window)	2.920
Pilaster 8	0.580

his façade based on his pre-existing house (Saalman 1988: 89), the internal layout of the underlying structure dictates how the façade had to be redesigned, directly influencing the varying width of the bays.

These variations complicate the reconstruction of the façade hypotheses. Hence, the largest measures of pilasters (0.670 m), window bays (2.920 m), and door bays (3.290 m), are employed in reference to the DT's plot boundaries (in green) to verify the different hypotheses' accuracy (Fig. 10). The 8-bay hypothesis takes the centre of the adjacent plot as its boundary. The alleged ruling design principle conforms to an AA-B-AA-B-AA width of the façade, meaning an alternation of two window bays (A) and the wider door bay (B). A similar sequence is followed for reconstructing the 11-bay hypotheses which results in a final AA-B-AA-B-AA-B-AA composition (Hersey 1976: 173). Comparing the discrepancy between the reconstructed façade width with the DT plot boundaries, shows a greater approximation error for the 8-bay hypothesis (2.84%), and a smaller one for the 9-bay and 11-bay hypothesis (1.74% and 1.37%) (Table 4). These errors fall well within expected discrepancies when considering their scale, differential measures, setting of the building, pre-existing conditions, and the variability of *braccia* units (Naredi-Rainer 1994; Frommel 2006). Moreover, the differential measures between the reconstructed ends of the 9-bay and 11-bay hypotheses, and the DT plot boundary, roughly equate to one Florentine *braccia*, meaning that it could have been used for creating a more harmonious façade ending. Based on these assertions, we can test the façade hypotheses on the DT model, by plotting their reconstructed visualisation on top of the street contours, including a permeable plan of the loggia as part of the streetscape. The *Isovist Area*, also included in the DT, shows changes of visuospatial properties in plan. Recently a VR of the palace reconstructions has been deployed to better explore their perception and triangulate the theoretical VGA results with virtual experiences (Pezzica et al. 2024).

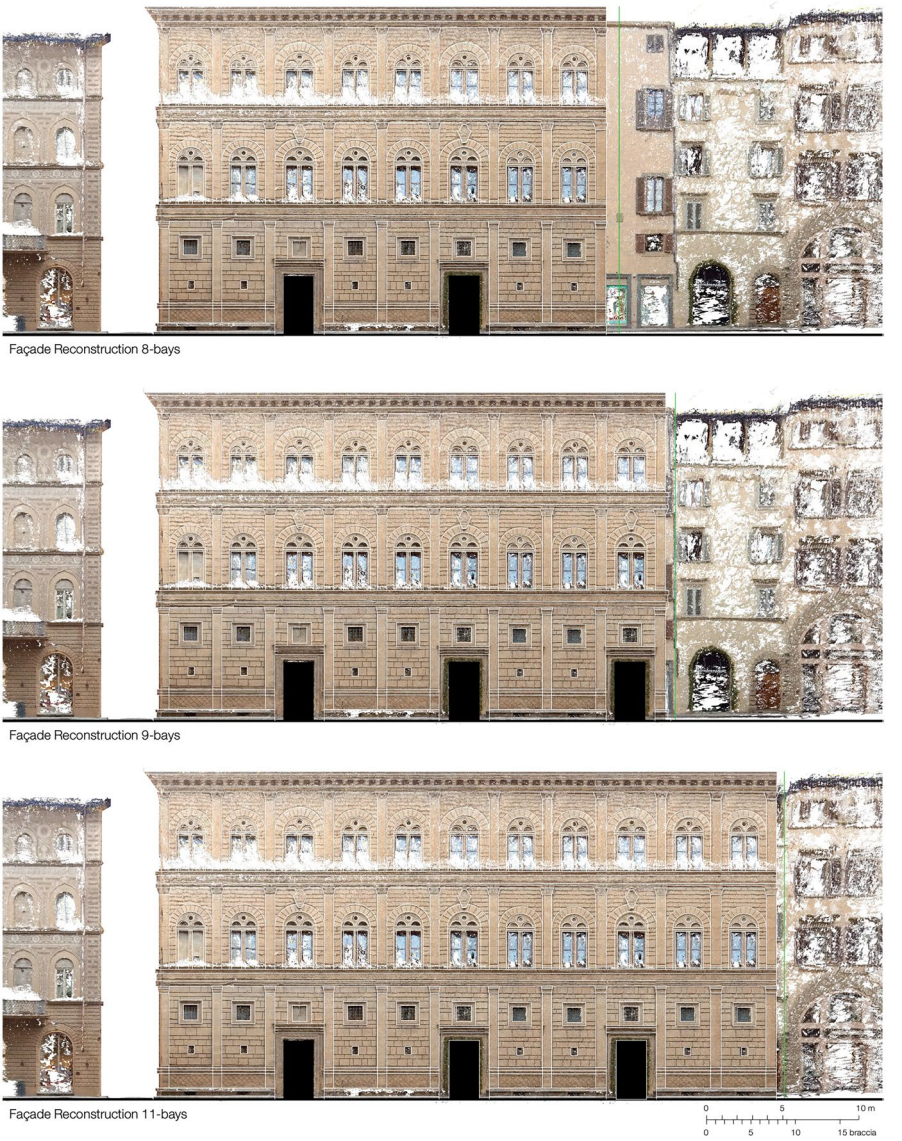

Fig. 10 Reconstruction diagram of the three finished façade hypotheses (8, 9 and 11 bays) for Palazzo Rucellai and DT plot boundary (green)

Table 4 DT measurement of the bay and pilasters of Pallazzo Rucellai

	Reconstruction	DT measure	Differential measure	Approximation Error
Hypothesis 1: 8-Bays	29.390 m	30.250 m	0.860 m	2.84%
Hypothesis 2: 9-Bays	33.350 m	33.940 m	0.590 m	1.74%
Hypothesis 3: 11-Bays	40.530 m	41.100 m	0.570 m	1.37%

Hypothesis 1–8 Bay Façade: The 8-Bay hypothesis seems the simplest and most obvious solution to the finishing of the palazzo façade as the existing unfinished façade already incorporates some of its initial blocks (Mack 1974). The 1994 Alberti exhibition held in Palazzo Te, Mantua, showed models of Alberti's oeuvre, including of Palazzo Rucellai (Rykwert and Engel 1994). The exhibition displayed a model of Palazzo Rucellai showing an 8-bay hypothesis, where the end of its façade aligns with the loggia (Ragazzo 1994). Proponents of the 8-bay façade disclose that with the completing of an 8-bay, the 9th bay (that would still be part of the plot) could form a street, thus creating a freestanding façade as per the Renaissance ideal. The approximation error of 2.84% does not impact the hypothesis, if a street would be made. Nevertheless, the street would lead nowhere, and such a new street nor the façade would align with the loggia or square. Indeed, these propositions received criticism for the inaccuracy of the model (Fiore and Adams 1995: 230), resulting in a distorted relationship between the loggia and the façade.

When relating the 8-bay hypothesis to Albertian theory, another anomaly arises as Alberti assumes that 'If the longer wall is to contain windows, they should be more frequent, and their number odd' (Alberti 1485: IX.3; Alberti 1988: 298). He even commences by stating 'Taking their [ancient] example from Nature, they never made the bones of the building, meaning the columns…, odd in number—for you will not find a single animal that stands or moves upon an odd number of feet' (Alberti 1485: IX.4; Alberti 1988: 303). While the even number of bays remains a possible solution within the context of the Florentine Quattrocento, it shows a discrepancy with Albertian theory. The attribution of the design to Alberti, as well as the established connection between Rucellai and Alberti, make the 8-bay hypothesis highly unlikely, even in the improbable case that Alberti did not design the façade. This claim further solidifies when envisioning the finished façade (Fig. 11). The *Isovist Area* map, indicating variations in the number of points in the direct environs of Palazzo Rucellai visible from each grid centroid in the VGA graph, does not align to the 8-bay façade (Preyer 1977: 183). Prior studies on determining the geometric alignment of the square equally do not support the 8-bay hypothesis (Mols and Pezzica 2023). Indeed, when envisioning the façade with 8 bays in an immersive environment, perceiving the palace from the middle of the square and looking towards the north edge of the palace, the visuospatial relationship is dissonant, meaning, the façade and loggia seem disconnected rather than forming a visually harmonious composition (Fig. 12). Hence, the discrepancies in its urban composition and discordance to Albertian theory make the 8-bay hypothesis a disputable case.

Hypothesis 2 – 9 Bay Façade: Building the 8-bay required Giovanni Rucellai to obtain the plot adjacent to his palazzo, which also fits the 9-bay hypothesis. The unfinished character of the existing palazzo insists that Giovanni envisioned to obtain at least this plot, making the 9-bay hypothesis as likely as the 8-bay one. The odd number of bays accords much better to Albertian theory, and equally shows a low approximation error (1.74%) in reference to the DT plot boundary. Yet, while it seems a more likely hypothesis than the 8-bay façade, it never received as much attention and popularity as its counterpart (Preyer 1981: 187; Mols and Pezzica 2023). When scrutinising the site and VGA analysis, the configurational index

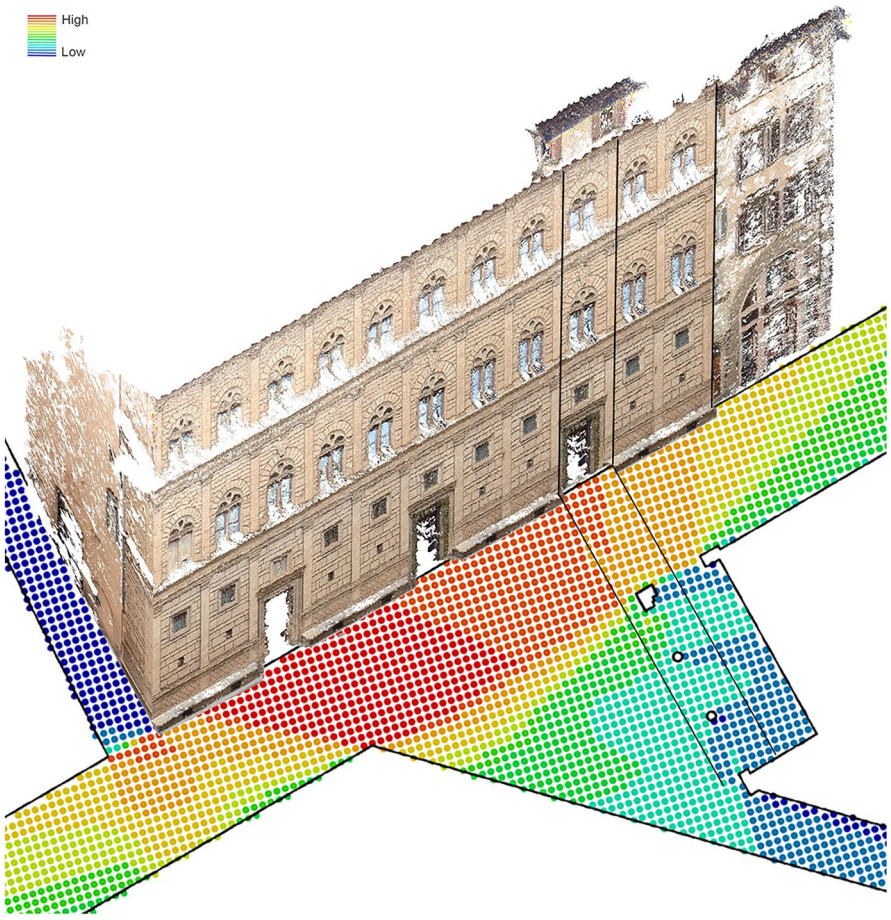

Fig. 11 Rucellai: 3D point cloud of the 11-bay façade and the *Isovist Area* of the piazza and loggia

shows a line marking a transition in configurational values that ends at the 9th bay (cf. Figure 11). While such an analysis does not prove historical accuracy, it lends more weight to the 9-bay hypothesis. Moreover, when perceiving the 9-bay façade reconstruction in VR, it visually aligns with the loggia, creating a more harmonious whole (cf. Figure 12). While the 9-bay hypothesis seems to work according to a conjoint reading of the VGA with Albertian theory, one cannot overlook the issue of the façade ending with a door bay rather than a window bay. Even when replacing the door with a window bay, the façade follows an AA-B-AA-B-AA-B sequence, which remains imbalanced.

The VR does recall Alberti's 'power of vision' and the importance of façades as the image of the cultural, intellectual, and political power of their owners (Alberti 2004: 39; Onians 1988: 182). Given the Rucellai's overt billowing sails and the Medici feathers being carved and painted into the very fabric of the Rucellai

Fig. 12 VR capture of Palazzo Rucellai's bay reconstructions. Image: Chiara Chioni 2023

façade and loggia the prominence of such vision-based claims is wholly convincing (Kent et al. 1981). Likewise, the almost perfect alignment with the loggia seems not coincidental but intentional even though the 9-bay hypothesis presents issues with the door position, raising more questions. Incorporating multiple doors into the façade equally exemplifies its ties to the Florentine urban fabric. The loggia and square, built to inaugurate the wedding of Giovanni's son Bernardo Rucellai (1448–1514) with Nannina de' Medici (1448–1493), aggrandised the image of the Rucellai (Preyer 1977: 188). In true Florentine fashion, the loggia was equally used for the family's business (Forster 1976: 109; Onians 1988: 185). Likewise, the numerous doors of the Palazzo seem to conform to the urban nature of its design. Seneca (c.4 BC–65 AD) explained the value of numerous doors for the functioning of a private residence, whereby one entrance was kept for the most important visitors, being the leftmost door in palazzo Rucellai, that situates at the end of the axis of the Via del Purgatorio, and directly leads to the main staircase and cortile. Other entrances could sequentially be used for inviting members of different ranks or disposing visitors without them losing face. The benches in front of Palazzo Rucellai, indeed indicate a mercantile function to the doors. Moreover, Alberti's *Tranquilità dell animo* was a free translation of Seneca's *De tranquillitati animi*, and Alberti even directly referred to Seneca's usage of doors in his *De re aedificatoria* (Albert Palatino ms; Alberti 1485: V.3). Moreover, Giovanni's *Zibaldone*, makes consistent references to Seneca, and interpreting the usage of the façade in this light strengthens the urban spirit of its design (Perosa 1960).

Hypothesis 3 – 11 Bay Façade: The misalignment of the 8th bays, and the discordant and untasteful door composition of the 9-bay urge for the reconsideration of the 11-bay façade. While farfetched as a design solution, since it requires two more plots for its completion, it may have been Giovanni's ultimate vision for his residence, and since he clearly envisioned buying one plot, the claim for the

Fig. 13 Left, Façade of the Spedale degli Innocenti by Brunelleschi, 1417–1436. Image: Wikimedia 2008 CC-BY-3.0; Right, Façade of the Santa Maria Novella by Alberti, c.1458–1470

purchasing of another seems plausible. While the Salviati painting seems to ground such claim, Hersey already asserted the 11-bay as the idealised solution (Hersey 1976: 173). Yet, Hersey did not provide great explanation for the hypothesis, nor did it rely on sufficient geometric data, which the present DT and VGA resolves. When comparing the 11-bay reconstruction with the DT boundary, it shows the lowest approximation error of the three hypotheses (1.37%) with a differential measure between the reconstruction and plot boundary of 0.570 m, roughly equivalent to a Florentine *braccio*. Like the 8-bay hypothesis, the 11-bay proposition contains a misalignment with the square and loggia. Yet, the presented 3D reconstruction enforces the visuospatial relationship between the palace and the square, where another *Isovist Area* threshold ends at the 11th-bay, even though not as evidently as for the 9-bay hypothesis (cf. Figure 11). A prior study equally indicated a geometric relationship between the square and the end of the 11-bay façade (Mols and Pezzica 2023). Moreover, the VR reconstruction shows that, when standing at the geometrical centre of the square, the observer's line of vision ties the palace façade to the loggia (cf. Figure 12). Not only does this mean that the alleged misalignment has a visual function known by Alberti, according to his *De pictura*, but also ensures that Piazza de' Rucellai is entirely dominated by Rucellai's edifices, reinforcing Giovanni's imprint on the Florentine streetscape.

Last, the façade reconstructions necessitate a solution for connecting to the adjacent buildings. For the 8-bay solution, theorised as a freestanding structure, widening the corner pilaster would solve this issue (Saalman 1988: 90). Yet, the 9- and 11-bay reconstructions require a more thorough design solution. The differential measures between the two hypotheses are 0.590 m and 0.570 m respectively, which may help solve this design problem (cf. Table 4). One design solution is to divide the measure over two bays with an additional 0.295 m, leading to a generic window bay of 3.215 m and door bay of 3.585 m for the 9-bay hypothesis. These variable measures seem aligned to the current bay variations. For the 11-bay hypothesis, the differential measure of 0.570 m divided over four bays, would lead to an additional 14.250 cm per bay, forming even less of a problem. The current façade already contains variable measurements for each bay, yet it does not disrupt the coherence of the façade. Such a façade treatment would, hence, suit both the 9- and 11-bay hypotheses. However, since the differential measure in both hypotheses roughly approximates one Florentine *braccio* (Naredi-Rainer 1982), another design solution

is possible. Namely, using the extra width to frame the building, either by doubling the end column, or placing a stringcourse along the entire height of the façade. While most Florentine palazzi don't show such a treatment, most Florentine palazzi equally don't contain carved pilasters. Yet some edifices built prior, or concurrent, to Palazzo Rucellai do contain a doubled column or stringcourse like Brunelleschi's Ospedale degli innocenti (Fig. 13). Likewise, Alberti's façade for the Santa Maria Novella also shows the combination of a half-protruding column with a widened pilaster at the corner (Fig. 14). The addition of an extra stringcourse or coupling a column would mark the end of the façade, making for a well-balanced and harmonious design decision. Rather than disproving the façade hypothesis, having such leeway allows for a more elaborate and mature finishing of the façade and makes the cases for both the 9-bay and 11-bay hypothesis much stronger.

Conclusion

By envisioning the visuospatial relationship of Florentine squares and palace façades in the cases of Palazzo Pitti, Strozzi, and Rucellai, this paper alluded to the intrinsic nexus between the perception of the façade and the urban role of palazzi architecture during the Quattrocento. While understanding the Renaissance façade as an agent of cultural magnanimity, artistic splendour, economic prosperity, and political power is not new (Grafton 2001: 8), the paper highlighted the cogent and persuasive role of the visual faculty in Renaissance architecture. Here visual perception relies as much on the image of architecture as it does on the urban space configuration to enable its fruition, underscoring Alberti's view of the house as a small city and vice versa (Alberti 1485: V.14; Alberti 1988: 140). Moreover, the conjoint reading of Giovanni's *Zibaldone*, and Albertian theory along a VGA and 3D DT reconstruction sets new light to the role of façades as agents of cultural expression and on Palazzo Rucellai's finished façade hypotheses, allowing to add to a long ongoing debate with their revisiting. As a result of the dissonance of the 8-bay within its architectural-urban context, the divergence from Albertian theory, and its unpersuasive perceptive power, the paper judges the 8-bay hypothesis as an unlikely contender. In contrast, the presented evidence highlights the high plausibility of the 11-bay hypothesis, while still acknowledging the theoretical and inconclusive nature of hypothetical assertions. The analysis of the broader contextualization of Palazzo Rucellai shows that, while unique in its conception, the palazzo was well entrenched in the Florentine context. This implies a revision of the claim that Palazzo Rucellai exerted limited influence on further developments in Florence (Forster 1976: 109). Indeed, while astylar façades reigned triumphant in Florence's Renaissance, some Florentine palaces did include columns, including the Palazzo Cocchi-Serristori (c.1495–1490), Palazzo Uguccioni (1550–1559), or Scamozzi's Palazzo Nonfinito (1593–1613). Beyond Florence, Baccio Pontelli and Antonio da Sangallo the elder's Palazzo della Cancellaria (1489–1513), or Vignola's, Ammanati's and Vasari's Villa Giulia near Rome (1551–1553), may have been inspired by Palazzo Rucellai. Finally, the paper rekindled the envisioned dream of Giovanni Rucellai for his unfinished palazzo, its design firmly ingraining itself in the course of western

architectural history, opening new avenues for future studies on the architectural-urban nexus in Renaissance Florence. Among others, further research on Palazzo Rucellai may include a comparative study of prior surveys with the 3D DT data and the use of a VR environment for further visual testing.

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References

Alberti, Leon Battista. 1435. *De pictura*. Florence: Nicolò di Lorenzo Alemanno.

[Alberti Palatino ms] Alberti, Leon Battista. [c.1441–42]. Ms *Della tranquillità dell'animo*. Florence, Biblioteca Nazionale Centrale di Firenze, Palatino 455.

Alberti, Leon Battista. 1485. *De re aedificatoria libri decem*. Florence: Nicolò di Lorenzo Alemanno.

Alberti, Leon Battista. 1988. *On the Art of Building in Ten Books*, transl. Joseph Rykwert, Neil Leach, Robert Tavernor. Cambridge, MA: The MIT press.

Alberti, Leon Battista. 2004. *On Painting*, transl. Cecil Grayson. Third edition. London: Penguin Books.

Andrews, David ed. 2009. *Metric Survey Specifications for Cultural Heritage*. Swindon: English Heritage.

Benedikt, Michael. L. 1979. To Take Hold of Space: Isovists and Isovist Fields. *Environment and Planning B: Planning and Design* 6 (1): 47–65. https://doi.org/https://doi.org/10.1068/b32067

Borsi, Franco. 1977. *Leon Battista Alberti, the Complete Works*. Milan: Electa.

Bulgarelli, Massimo. 2006. Leon Battista Alberti a Firenze, Stabili e irrequiete: le facciate di Palazzo Rucellai e di Santa Maria Novella. *Casabella* 747: 44-55.

Cutini, Valerio. 2003. Lines and Squares: Towards a Configurational Approach to the Morphology of Open Spaces. *Proceedings of the 4th International Space Syntax Symposium*, London.

Feola, Franco. 2006. L'architettura del numero e del suono: Il legame tra architettura, musica e matematica nella facciata di Palazzo Rucellai di Leon Battista Alberti. In *Arte e matematica: in sorprendente binomio*, ed. E. Ambirsi. Naples: Instituto Italiano per gli Studi Filosofici: 193–205.

Fiore, Francesco Paolo and N. Adams. 1995. Leon Battista Alberti. *Journal of the Society of Architectural Historians* 54 (2): 228–232.

Forster, Kurt. 1976. The Palazzo Rucellai and Questions of Typology in the Development of Renaissance Buildings. *The Art Bulletin* 58 (1): 109-113.

Frommel, Christoph L. 2006. Palazzo Rucellai. In *Leon Battista Alberti e l'architettura*, ed. Massimo Bulgarelli. Milan: Cinisello Balsamo: 344–47.

Gaborit, Jean-René. 2013. Il palazzo patrizio e i suoi ornamenti scultorei. In *La primavera del Rinascimento: la scultura e le arti a Firenze, 1400–1460*, eds. Beatrice Paolozzi Strozzi, Marc Bormand. Florence: Mandragora: 237–45.

Gombrich, Ernst H. 1972. *Art and Illusion, a Study in the Psychology of Pictorial Representation*. Fourth edition. London: Phaidon.
Goy, Richard. 2002. *Florence, the City and its Architecture*. London: Phaidon.
Grafton, Anthony. 2001. *Leon Battista Alberti, Master Builder of the Italian Renaissance*. London: Penguin Books.
Gurrieri, Francesco. 2009. Palazzo Rucellai. In *La città a pezzi, pezzi di città: distacchi lapidei a Firenze: 1977–2009*, ed. Francesco Gurrieri. Florence: Polistampa: 58–60.
Hersey, George L. 1976. *Pythagorean Palaces, Magic and Architecture in the Italian Renaissance*. Ithaca: Cornell University Press.
Hillier, Bill. 2007. *Space is the Machine*. Online edition. London: University of Cambridge. https://spaceisthemachine.com/
Hillier, Bill and Julienne Hanson.1984. *The Social Logic of Space*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511597237
Kemp, Martin. 2006. *Seen | Unseen, Art, Science, and Intuition from Leonardo to the Hubble Telescope*. Oxford: Oxford University Press.
Kent, William F., Alessandro Perosa, Brenda Preyer, Piero Sanpaolesi et al. 1981. *Giovanni Rucellai ed il suo 'Zibaldone' vol 2. A Florentine Patrician and his Palace*. London: University of London, The Warburg Institute.
Koutsolampros, P., K. Sailer, Tasos Varoudis and R. Haslem. 2019. Dissecting Visibility Graph Analysis: The Metrics and their Role in Understanding Workplace Human Behaviour. *Proceedings of the 12th Space Syntax Symposium* 191:7–191:24.
Mack, Charles Randall. 1974. The Rucellai Palace: Some New Proposals. *The Art Bulletin* 56 (4): 517-529.
Mols, Nick. 2019. Sebastiano Serlio's Spatial Representation through Linee Occulte. *Thinking 3D*. https://www.thinking3d.ac.uk/Serlio_Linee-occulte/
Mols, Nick and Camilla Pezzica. 2023. Florentine Streetscapes and their Role in Revisiting Palazzo Rucellai's Urban Façade Hypotheses. *Nexus Network Journal* 25: 47-54. Doi: https://doi.org/10.1007/s00004-023-00698-0
Montigny, Auguste Grandjean de and Auguste Famin. 1806. *Architecture toscane: palais, maisons, églises et autres édifices publics et privés principalement des 15e, 16e, et 17e siècles*. Paris: P. Didot l'ainé.
Naredi-Rainer von, Paul. 1982. *Architektur und harmonie. Zahl, maß und proportion in der abendländischen baukunst*. Cologne: DuMont.
Onians, John. 1988. *Bearers of Meaning: The Classical Orders in Antiquity, the Middle Ages and the Renaissance*. Princeton: Princeton University Press.
Payne, Alina A. 1999. *The Architectural Treatise in the Italian Renaissance, Architectural Invention, Ornament, and Literary Culture*. Cambridge: Cambridge University Press.
Pearson, Caspar. 2011. *Humanism and the Urban World: Leon Battista Alberti and the Renaissance City*. University Park: Penn State University Press.
Pearson, Caspar. 2022. *Leon Battista Alberti: The Chameleon's Eye*. London: Reaktion Books.
Perosa, Alessandro. 1960. *Giovanni Rucellai ed il suo 'Zibaldone' vol 1. Il Zibaldone Quaresimale*. London: University of London, The Warburg Institute.
Pezzica, Camilla, Chiara Chioni and Nick Mols. Forthcoming 2024. Exploring Alternative Urban and Architectural Virtual Realities through Multidomain Digital Twins. In *Advances in Representation. New AI- and XR Driven Transdisciplinarity,* eds. Giordano Andrea, Michele Russo, Roberta Spallone. Springer: 1–16.
Preyer, Brenda. 1977. The Rucellai loggia. *Mitteilungen des Kunsthistorischen Institutes in Florenz* 21 (2): 183–98.
Ragazzo, Felice. 1994. I modelli lignei delle opera di Leon Battista Alberti alla mostra di Palazzo Te. In *Leon Battista Alberti,* eds. Joseph Rykwert, Anne Engel. Milan: 408–411.
Rykwert Joseph, Anne Engel. 1994. *Leon Battista Alberti*, Exhibition Catalogue, Palazzo Te, Mantua.
Saalman, Howard. 1988. Palazzo Rucellai. *The Journal of the Society of Architectural Historians* 47 (1): 82–90.
Samperi, Renata. 2005. Capitelli. In *La Roma di Leon Battista Alberti, architetti, umanisti e artisti alla scoperta dell'antico nella città del Quattrocento*, Francesco paolo Fiore ed. Milan: Skira: 259–266.
Sanpaolesi, Paolo. 1963. Precisazioni su Palazzo Rucellai. *Palladio* 13: 61-67.
Schlosser von, Julius. 1924. *Die kunstliteratur, ein handbuch zur quellenkunde der neueren kunstgeschichte*. Vienna: Anton Schroll & co.

Stegmann von, Carl and Heinrich von Geymüller. 1885–1907. *Die architektur der renaissance in Toscana*, 3 vols. Munich: Bruckmann.

Turner, Alasdair. 2007. From Axial to Road-Centre Lines: A New Representation for Space Syntax and a New Model of Route Choice for Transport Network Analysis. *Environment and Planning B: Planning and Design* 34 (3): 539–555. https://doi.org/https://doi.org/10.1068/b32067

Turner, Alasdair, Maria Doxa, David O'Sullivan and Alan Penn. 2001. From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space. *Environment and Planning B: Planning and Design* 28: 103–121. https://doi.org/https://doi.org/10.1068/b268

Trachtenberg, Martin. 1997. *Dominion of the Eye: Urbanism, Art and Power in Early Modern Florence*. Cambridge: Cambridge University Press.

Varoudis, T. (n.d.). Depthmap X by Varoudis. available via https://varoudis.github.io/depthmapX/ (accessed 29 December 2023).

Vasari, Giorgio. 1550. *Le Vite de'più eccellenti pittori, scultori, e architettori*. Florence: Torrentino.

Waldman, Louis and Brenda Preyer. 2010. The Rise of the Patronage Portrait in Late Renaissance Florence: An Enigmatic Portrait of Giovanni di Paolo Rucellai and its Role in Family Commemoration. *Mitteilungen des Kunsthistorischen Institutes in Florenz* 54 (1): 133-54.

Welch, Evelyn. 1997. *Art in Renaissance Italy.* Oxford: Oxford University Press.

Wittkower, Rudolf. 1967. *Architectural Principles in the Age of Humanism*. Fourth edition. London: Alec Tiranti.

Wood, Christopher. 2019. *A History of Art History*. Princeton: Princeton University Press.

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