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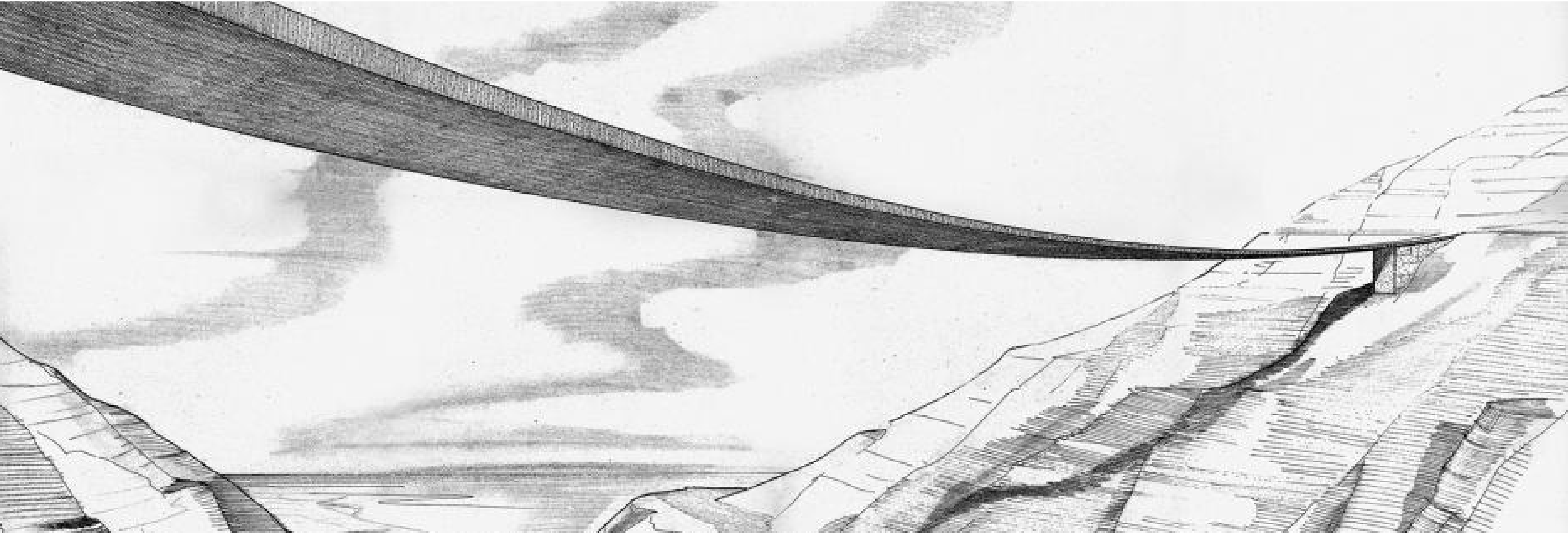

diségno

17.2025

THE REVEALED STRUCTURE.
DRAWING BETWEEN CONSTRUCTION AND FORM

diségno

unione italiana disegno

Biannual Journal of the UID Unione Italiana per il Disegno Scientific Society
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Cover
Bridge over the river Guayllabamba, competition project. Perspective view, detail (Historical Archive of the Politecnico di Milano, Silvano Zorzi Collection, Milan).

The published articles have been subjected to double blind peer review, which entails selection by at least two international experts on specific topics.
For Issue No. 17/2025, the evaluation of contributions has been entrusted to the following referees:
Fabrizio Agnello, Giuseppe Amoruso, Fabrizio Avella, Enrico Babilio, Laura Baratin, Alessio Bortot, Adriana Caldarone, Daniele Calisi, Cristina Càndito, Mara Capone, Nicola Cavalagli, Vincenzo Cirillo, Daniele Colistra, Fabio Colonnese, Giuseppe D'Acunto, Pia Davico, Andrea Di Filippo, Antonella di Luggo, Francesco Di Paola, Edoardo Dotto, Federico Fallavollita, Marco Fasolo, Riccardo Foschi, Manuela Incerti, Elena Ippoliti, Emanuela Lanzara, Gabriella Liva, Massimiliano Lo Turco, Francesco Maggio, Domenico Mediati, Alessandra Meschini, Daniela Palomba, Leonardo Paris, Maria Ines Pascariello, Manuela Piscitelli, Leopoldo Repola, Jessica Romor, Michele Russo, Alberto Sdegno, Giovanna Spadafora, Roberta Spallone, Maurizio Unali, Rita Valenti, Daniele Villa

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Editorial

Ornella Zerlenga

The first issue of *diségno*, the biannual journal of the scientific society Unione Italiana per il Disegno, was published in December 2017 and continued with regular periodicity through December 2025, reaching issue no. 17. Overall, this amounts to eight years of scientific activity, during which the patient, competent, and courageous work –initially of Vito Cardone, UID President, founder of the journal and its first Editorial Director, and subsequently of Francesca Fatta, who succeeded Cardone as UID President and served as Editorial Director for two terms– together with that of the Editorial board across its three components (scientific committee, coordination, and staff), led to the online Open Access publication of 16 issues. These were characterized by diverse calls for papers and included nearly 250 articles selected through a double-blind peer review process, in addition to invited contributions. This was complemented by editorial coordination for the preparation of the journal's sections: *Image*, *Readings/Rereadings*, *Reviews*, *Events*, and *The UID Library*. This rigorous scientific and editorial effort progressively enabled *diségno* to achieve significant milestones: inclusion, as early as April 2020 (retroactively from its first issue), in the list of scientific journals for Area 08 compiled by Anvur; indexing in Scopus in March 2021; and recognition by Anvur in September 2025 as a Class A scientific journal for the competition sectors ex 08/C1, 08/D1, and 08/E1 (effective from January 2021).
This long-awaited success, announced by Francesca Fatta in the *Editorial* of issue no. 16/2025, deserves to be reiterated here as a milestone that makes the UID scientific association and the disciplinary field of Drawing proud. It acknowledges both Francesca Fatta –who, inheriting the journal's management, together with the Editorial board - coordination and staff, brought *diségno* to Class A status– and Vito Cardone, promoter of the project that endowed UID with a scientific journal, as provided for in its Statute and Regulations, and described as an "important event, especially when it has been awaited for years" [Cardone, Editorial. In *diségno*, no. 1/2017, p. 5]. To both, sincere thanks are due.
Before outlining the contents of issue no. 17, I would like to echo Francesca Fatta's wish for "a long life to the journal and its renewal under the direction of Ornella Zerlenga" [Fatta, Editorial. In *diségno*, no. 16/2025, p. 6]. Indeed, this issue falls within the new UID three-year term 2024-2027, following the election, in September 2024, of the new Scientific-Technical Committee (CTS) and, subsequently, the President. The colophon of this issue thus reflects an updated configuration of roles and members, including Marco Giorgio Bevilacqua, Stefano Brusaporci, Marianna Calia, Stefano Chiarenza, Emanuela Chiavoni, Luigi Cocchiarella, Laura Farroni, Vincenza Garofalo, Valeria Menchetelli, Anna Osello, Sandro Parrinello, and Cettina Santagati.
Furthermore, both the CTS and the Editorial Board have expressed the desire to preserve in the colophon the memory of Massimiliano Ciammaichella, who passed away prematurely in August 2025, having been re-elected with full votes to the CTS for 2024-2027 and reconfirmed in the Editorial board - coordination. In September 2025, the Assembly of Members decided to dedicate issue no. 18 of the journal to his memory.
Issue no. 17 of *diségno* is therefore marked by multiple emotions: the transition of leadership, but above all the awareness of inheriting a significant legacy, representing an important chapter in the history of UID and an excellent achievement. On this basis, the Editorial board developed several reflections aimed at improving the performance of the call launch, the selection of contributions, and the alignment of the journal's sections with the call's theme. Sharing the view that guest editors, as authors of the call, possess full decision-making competence, those external to the CTS were invited to participate in Editorial board decisions during the preparation of the issue, thereby contributing to optimizing both the acceptance process of submitted papers and the content of the sections. A new development concerns the *Reviews* section, in which it has been decided to highlight books relevant to the call published from the current semester back to 2016, the year in which systematic collection of UID members' scientific publications began. Moreover, thanks to synergy with *The UID Library*, in addition to the list of recent volumes, readers can access a further selection of texts curated by Vincenzo Cirillo and Laura Farroni, related to the call, as well as consult online the recording of the presentation held within the series *1 Libro: 1 Disegno* (coordinated by Farroni).

Turning to the theme of the call for papers for issue no. 17, in agreement with the Editorial board –scientific committee and coordination–, the call was launched by Stefano Chiarenza and Marta Salvatore. Its title reflects their scientific and cultural background and research interests, offering the disciplinary community an opportunity to reflect on the role of theoretical foundations and, in particular, on the science of representation as a conscious mediator both in the creative phases of design development and in those concerning the transcription of reality for the knowledge of cultural heritage. Entitled *The Revealed Structure. Drawing between Construction and Form*, the call aimed to foster a non-antagonistic dialogue, avoiding unproductive oppositions –such as theory versus practice, analogue versus digital, real versus virtual, and more recently 'organic' versus 'artificial' intelligence– and instead creating opportunities for critical thinking capable of updating the historical and foundational dimension of Drawing in relation to rapidly evolving cultural, technological, and ethical contexts. In essence, it invited reflection on key questions: What is the value today of knowledge of the theoretical foundations of the discipline in the construction of critical thought? Is it still possible to assert that geometric knowledge and digital representation should converge toward a single objective – the 'mental control' of spatial problems? Does the configuration of a structure beyond the visible represent its formal essence? And, as stated in the call, is Drawing "the medium through which the invisible takes shape"? In response to these questions, the guest editors propose "reflections on the role of drawing in the representation of structure as the visible form of technical and design thinking" structured into four thematic focuses, each introduced by an invited contribution. The first, *Structures Made Visible. Drawing as Constructive Revelation*, explores drawing as a medium that renders visible the relationship between form, structure, and geometry, and is introduced by Cosimo Monteleone (University of Padua), whose early education in geometrical-descriptive spatial analysis took place at the Iuav University of Venice under Agostino De Rosa. The second, *Forms of Resistance. Structural Aesthetics and Imaginary*, is introduced by American artist Kristin Jones, who, through a suggestive and symbolic interpretation, uses drawing to express her conception of the geometric configuration of the Pantheon in Rome – serving as a theoretical premise for her installation project within this space and as a stimulus for analyzing structures as outcomes of visual culture. The third, *Drawing the Structure. Codes, Methods, and Tools*, opens with an essay by Luigi Cocchiarella (Politecnico di Milano), whose rigorous scientific training –developed in Naples under Anna Sgrosso, Rosa Penta, Mariella Dell'Aquila, and Vladimiro Valerio– provides the basis for introducing Descriptive Geometry, digital modeling, and computational simulation in a dialogic reading between traditional and innovative tools in drawing. The fourth focus, *The Aesthetics of Logic. Form, Structure, and Design*, is introduced by Francesco Romeo (Sapienza Università di Roma), who, referring to the ribbed slabs of Pier Luigi Nervi, addresses the design dimension of structure as a generator of form.

In addition to the guest editors' essay and the four invited contributions, issue no. 17/2025 includes 17 articles selected from submissions, for a total of 22 essays (many authored by international scholars), addressing the call from multiple perspectives. This constitutes a substantial response to a topic that is only apparently outdated or niche. Complementing this is Fabrizio Gay's critical reading, in the *Image* section, of the drawings selected by the guest editors: Luigi Walter Moretti's sketch drawings for the project of the Teatro Imperiale at the E42.

The journal sections are equally substantial. For *Readings/Rereadings*, Federico Fallavollita revisits *La représentation des structures constructives* by Adrian Gheorghiu and Virgil Dragomir (Bucharest, 1968; French translation the same year), described as "a true treatise on the profound relationship between form, structure, and representation, capable of speaking even today to architects, engineers, and scholars concerned with the logic of spatial configuration" [p. 315]. For the *Reviews* section, Cristina Càndito, Vincenzo Cirillo, and Alessio Bortot review selected monographs (2016-2025) relevant to the call, authored respectively by Mara Capone, Matteo Flavio Mancini, and Francesco Di Paola with Andrea Mercurio. For *Events*, Paolo Giandebiaggi reports on the 46th UID Conference held in Rome, while Giovanni Albini, Marcello Balzani, Emanuela Lanzara, Valeria Menchetelli, and Maria Zack present UID-sponsored initiatives: *ICGG2024*, *PhD UID Summer School 2025*, *APEGA 2025*, *Alghero Week 2025*, and *Nexus 2025*. The issue concludes with the renewed section *The UID Library* and the report *UID Awards 2025*.

In conclusion, the preparation of issue no. 17 of *diségno*, the result of collective work, has been both emotionally engaging –due to the chosen theme and the shared reflections initiating a process of renewal– and marked by anticipation, owing to the prolonged and unpredictable technical timelines related to the registration of the new Editorial Director with the special register of the Order of Journalists of Campania and the journal's registration with the Court of Naples. Nevertheless, reflecting the shared sentiment of all those involved in this issue, no. 17/2025 inaugurates the 2024-2027 term with a hope: that *diségno* will continue to confirm the scientific and cultural relevance it has demonstrated thus far, and serve as a primary reference for reflecting on what the discipline of Drawing represents today and how essential its past remains for adapting, with awareness, to ever more rapidly changing times. And, as Vito Cardone urged in his first *Editorial*, that we may devote ourselves to the study of "all drawings" so that the journal may increasingly become a 'place' for the development of innovative reflections.

The Revealed Structure. Drawing between Construction and Form

Stefano Chiarenza, Marta Salvatore

Configuring and revealing: drawing and structural order

The coherence of built architecture often depends on a latent structural design whose essential role can govern architectural outcomes even when not overtly visible. Structural logic is either integrated into the building as a whole or concealed behind finished surfaces. However, this concealed structure often defines space and regulates formal relationships. Instead of viewing structure and form as opposites or as directly corresponding, it is more accurate to understand them as mutually influential, their relationship shaped by specific design choices. Every construction act creates an order, and every form manifests through its underlying structure, highlighting an ongoing interplay between these elements.

What Leon Battista Alberti defined as the "*armonia delle parti in relazione a un tutto al quale esse sono legate secondo un determinato numero, delimitazione e collocazione*" [Alberti 1966, p. 816] [1] in fact expresses a principle of ethical –or, if one prefers, tectonic– and aesthetic coherence at once. This principle has long constituted the foundation of architecture. It refers to a fundamental system of relationships that also permeates other fields of knowledge, from structural mechanics to evolutionary biology and even the theory of complex systems.
Structural order, whether perceptually implicit or explicit, does not preclude aesthetic experience. One might instead argue that it determines it. When Ludwig Mies van der Rohe stated that function is an art [Mies van

This article was written upon invitation to frame the topic, not submitted to anonymous review, published under the editorial director's responsibility.

der Rohe 1953, p. 276], he understood the essence of architectural beauty as the perfect harmony between structural order and form: a form that is recognizable and meaningful, determined by the structure that enhances its expressive value. As Curt Siegel observes, "the prominent vault ribs of the great Gothic cathedrals are not merely decorative trimming. They are themselves part of the structure and splendid examples of structural form" [Siegel 1962, p. 10] (fig. 1).
Aesthetic experience is not foundational, yet it cannot be separated from the relationships that enable it. "Such is the case with the most perfect and appealing creations of Nature […] whose outer beauty is deeply influenced by the perfection of the skeleton, which itself is unattractive but does enhance the poetry of the whole by its own indirect means of expressiveness" [Torroja 1967, p. 268] (fig. 2).
In architecture and structural engineering, order therefore assumes the character of an organizational principle internal to construction; structure constitutes the relational law governing the elements, which can be formalized through geometric rules [Strappa 1995]. Form thus does not appear as an arbitrary outcome, but as the legible configuration of this system of relationships. In certain cases, it coincides with what is referred to as structural form, which nonetheless retains intrinsic autonomy and can guide particularly effective design choices. This autonomy emerges when form renders recognizable the order that generates it, revealing structure as an active principle rather than merely a technical solution (fig. 3).
A similar principle can be observed in natural morphogenetic processes, in which biological form arises from the interaction of geometric constraints, growth dynamics, and environmental conditions. Even in the absence of a dynamic formalization, Thompson had already recognized physical and geometric factors as the principal generators of form [Thompson 1969] (fig. 4).
Today, advanced dynamic theories of morphogenesis – from the reaction–diffusion models developed by Alan Turing [Turing 1952] to fractal growth models– reveal

Fig. 1. Guillermo Sagrera, Castel Nuovo, Sala dei Baroni, Naples. Ribbed vault, fifteenth century (photograph by Miguel Hermoso Cuesta; source: <https://upload.wikimedia.org/wikipedia/commons/3/39/Castel_Nuovo_Sala_dei_Baroni_07.JPG>).

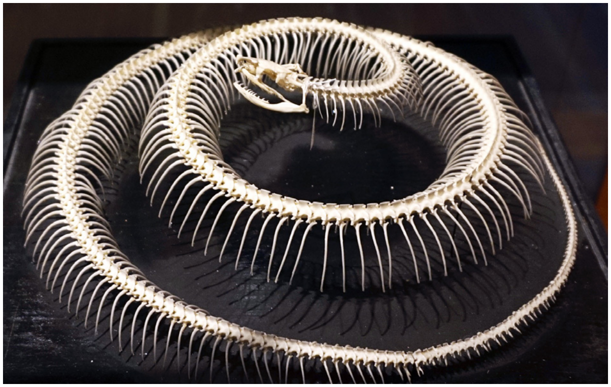
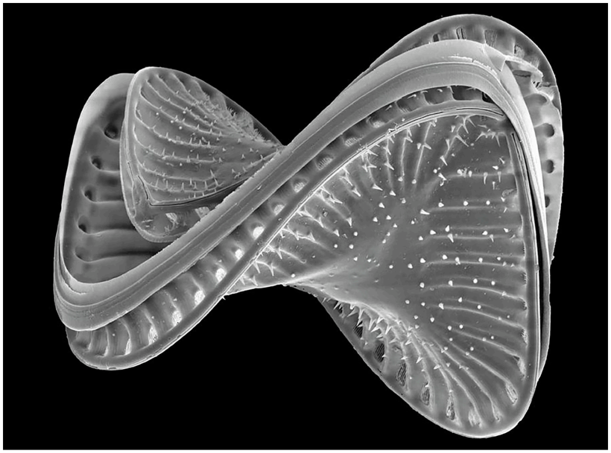


Fig. 2. Snake skeleton (photograph by Tiia Monto; source: <https://commons.wikimedia.org/wiki/File:Snake_skeleton_3.jpg>).



how complex natural forms, from the venation patterns of leaves to the logarithmic spirals of shells and the convoluted cortical structure of the brain, can be generated and understood through rigorous mathematical models. These models formalize non-linear dynamics in which regimes of stability, instability, and complex attractors emerge spontaneously from the elementary interactions of morphogenetic fields [Petitot 2009]. Establishing a parallel between natural and artificial processes in architecture is therefore not merely coherent but essential, insofar as both classes of phenomena obey shared emergent logics. Form thus emerges as the result of systemic interactions between energy, information, and matter, governed by universal topological and relational principles [De Paolis 2020].

Computational architecture and generative design develop these ideas in concrete and innovative ways, effectively transforming the design process itself. According to this approach, architectural form should be understood as the inevitable outcome of processes – such as parametric modeling, topological optimization, and structural simulations– that rigorously integrate construction constraints, material properties, and loading conditions into defined and verifiable algorithmic rules. It emerges as the visible and performative configuration of a complex web of relationships, fully analogous to the natural growth phenomena previously outlined [Menges 2011], in which an underlying order generates emergent complexity. The synergy between advanced digital design, smart materials, and computational morphogenetic logics demonstrates in exemplary and empirically validated ways how form derives from a deep order that inseparably binds space, structure, and matter within a coherent and functional system [Ramirez-Figueroa, Dade-Robertson, Hernán 2013] (fig. 5).

From a theoretical and philosophical perspective as well, the question of an order that precedes and guides

Fig. 3. Santiago Calatrava, OAKA Olympic Stadium, Athens, 2004 (photograph by Georgios Liakopoulos; source: <https://commons.wikimedia.org/wiki/File:Calatrava_Agora_Athens_Olympic_Sports_Complex_%28250427331%29.jpeg>).

Fig. 4. Top: Campylodiscus clypeus (source: <https://www.sciencephoto.com/media/891862/view>); bottom: Félix Candela, Chapel of Lomas, Cuernavaca, 1958–1960 (source: <https://www.flickr.com/photos/147316538@N02/36084417680>).

form finds solid grounding, as demonstrated by theories of adaptive morphogenesis and data-driven generative processes [Nebuloni, Buratti 2023]. If form can be conceived as the inevitable product of an underlying structural stability –a deep relational order that generates its essence– and if beauty manifests itself as the harmonious expression of such order, then the question inevitably arises of how this invisible dimension may be rendered legible within built matter. Here, drawing assumes a fundamental and irreplaceable role in the processes through which form is both structured and revealed.
On the one hand, it functions as an instrument of primary configuration. Through drawing, it becomes possible to regulate space, define the genesis of surfaces through geometric operations, and manage the generative processes that determine the geometric and material articulation of the project. In this context, drawing represents the locus in which formal decisions acquire concrete expression, guiding the project from its earliest conceptual stages in accordance with the structural order being articulated.
On the other hand, drawing acts as a revealing instrument. It does not constitute a direct transcription of structure but rather an operation of abstraction and selection that establishes a distance between representation and building (fig. 6). What in construction is embedded in matter –static relationships, geometric hierarchies, and the distribution of stresses– is, in drawing, isolated and reorganized according to its own order [Pérez-Gómez 1982]. Within this interval, structure becomes intelligible, assuming a form that corresponds neither to the initial idea nor to the built work. As Robin Evans outlined, the passage from drawing to building always entails a transformation, in which something is lost, and something is reorganized, thereby generating a system of relations endowed with its own coherence [Evans 1997]. Within this redefinition, geometry

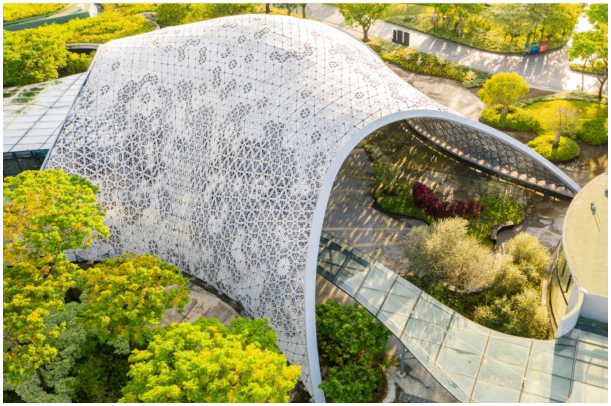


Fig. 5. SUTD Advanced Architecture Laboratory, The Future of Us Pavilion, Singapore (source: <https://loopdesignawards.com/project/the-future-of-us-pavilion/>).

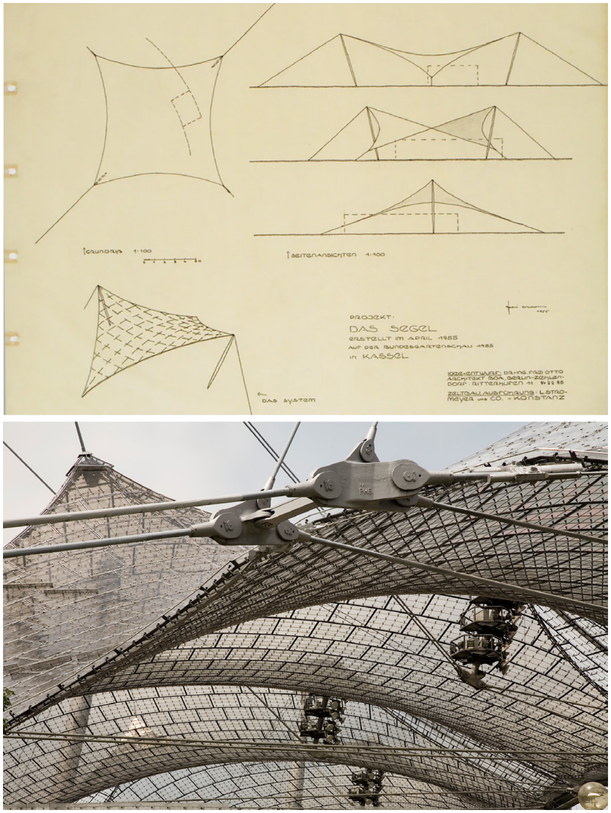


Fig. 6. Frei Otto, examples of tensile structures. Top: graphic diagrams of the Musikpavillon, Kassel (<http://www.freiottofilm.com>); bottom: detail of structural elements of the roof of the Olympic Stadium, Munich (bottom) (source: <https://upload.wikimedia.org/wikipedia/commons/0/06/Munich_-_Frei_Otto_Tensed_structures_-_5244.jpg>).

operates as a configurational instrument, making explicit the relationships that compose form.
Drawing thus emerges as the essential locus in which the structural order of form becomes legible through rigorous geometric operations that isolate and abstract the relationships between the graphic model and the built space [Rykwert 1998]. Relationships of curvature, alignments, and conditions of planarity or developability –embedded in the surface continuity of construction– are made explicit as verifiable relations.
Representation thereby assumes a specific epistemic value: it renders measurable and comparable the conditions that determine the construction of form, which may be interpreted as a system of correlated elements and constraints. Structure appears as a network of geometric and static relationships in which formal continuity results from a balance between discretization, approximation, and constructive coherence (fig. 7).
This legibility of structural order, emerging in drawing as a verifiable and autonomous geometric configuration, not only clarifies the potential for realization of form but also raises crucial questions concerning the cognitive and operational value of representation itself, paving the way for an analysis of its mediating role in the genesis of architecture.
Within this framework, drawing is not merely a means of translation between idea and construction, but the instrument through which the relationship between structural order and form is realized. This function is neither a recent acquisition nor one exclusively tied to contemporary computational practices; rather, it is rooted in a well-defined theoretical and practical tradition in which geometry historically constituted the language through which form was constructed and validated. It is within this tradition that drawing assumes a central role in knowledge and design processes, starting a reflection on the contribution of synthetic geometry to the construction of architectural form.

Visible form of design thought

Drawing, a universal language for communicating space through visual descriptions, reveals its heuristic value in the relationship between construction and form, expressing its constructive dimension through the research and control of the geometric properties of figures.
The cognitive potential of drawing finds its theoretical foundation in synthetic geometry. Geometry serves to translate the morphological properties of figures into conceptual and operational tools for design, and has been employed for this purpose since ancient times. The properties of certain classes of surfaces encouraged their use in construction, first in an intuitive manner and later with conscious and controlled application. History records a vast repertoire of works whose formal structure is based on geometry, enabling the identification of specific fields of application of this science in design, which contributed to the development of Descriptive Geometry, anticipating some of its principles. Among these, the art of stone cutting is exemplary, as it represents a synthesis of morphological control, rigorous representation, and constructive awareness (fig. 8).
Synthetic geometry, rooted in antiquity, acquired a modern form between the late eighteenth and early nineteenth centuries. At the time when Gaspard Monge wrote his *Leçons* in Descriptive Geometry, there was a need to establish a method for studying geometry that could stand alongside mathematical methods, founded on logical reasoning and supported by the science of projections [2]. Monge's Descriptive Geometry recognized drawing as the tool through which the synthetic method could measure itself against contemporary rigorous analytical descriptions, distinguishing itself by the clarity of its reasoning, the simplicity of its demonstrations, and the effective application of theorems; his scientific output clearly exemplifies this approach [3].
In his *Cours de Géométrie descriptive*, Théodore Olivier recounts how Monge attempted to demonstrate the contents of his *Analyse appliquée à la géométrie* using the methods of Descriptive Geometry, citing one of his own significant reflections: "*Si je refaisais mon ouvrage qui a pour titre* de l'analyse appliquée à la géométrie […] *je l'écrirais en deux colonnes: dans la première, je donnerais les démonstrations par l'*analyse*; dans la seconde je donnerais les démonstrations par la* géométrie descriptive*, en d'autre termes, par la méthode des projections; et l'on serait peut-être, ajoutait-il, bien étonné, en lisant cette ouvrage, de voir que l'avantage serait presque toujours du côté de la seconde colonne, pour la clarté du raisonnement, la simplicité de la démonstration, et la facilité de l'application des* théorèmes *trouvés aux diverses* travaux *des* ingénieurs" [Olivier 1843, p. VI] [4].

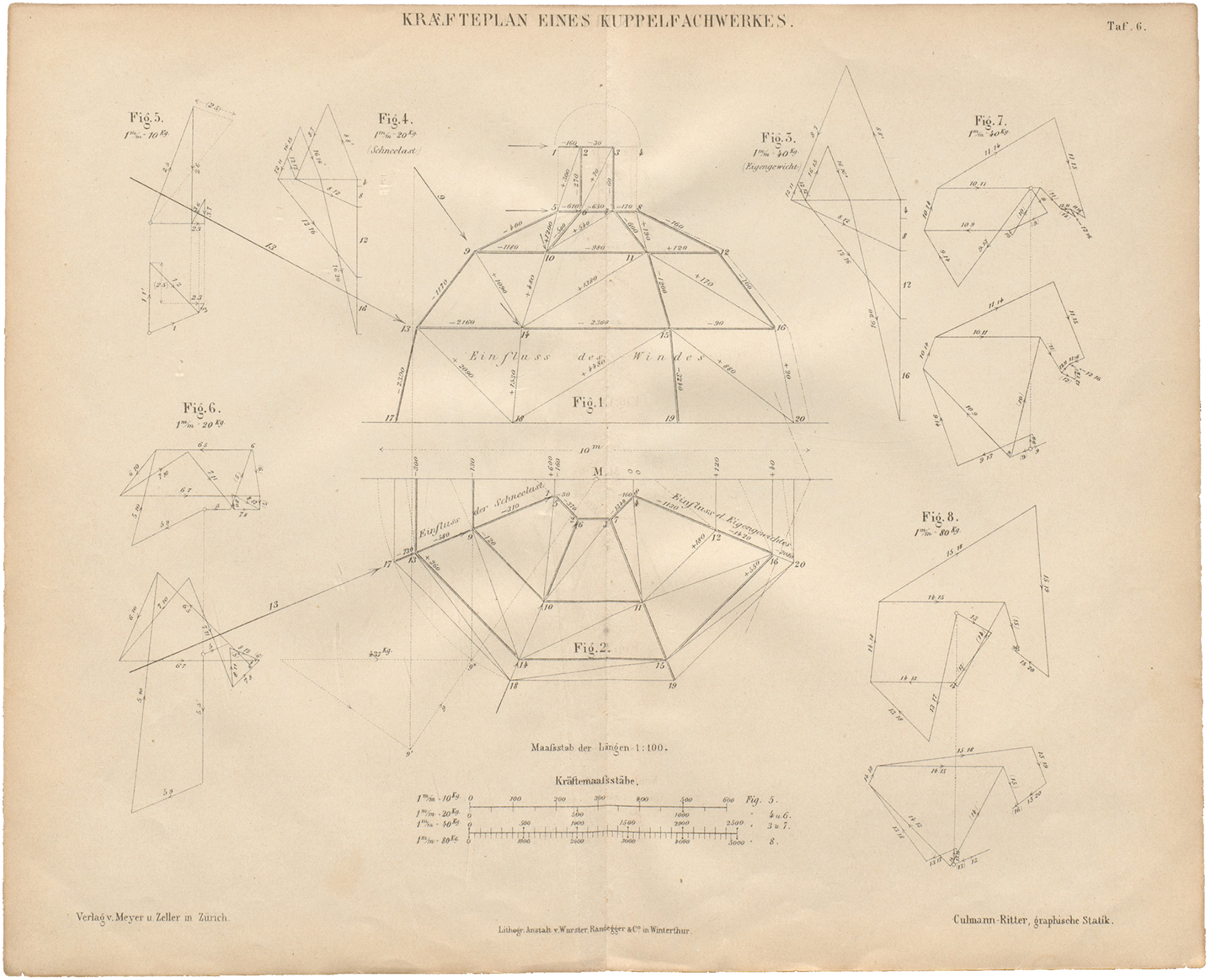
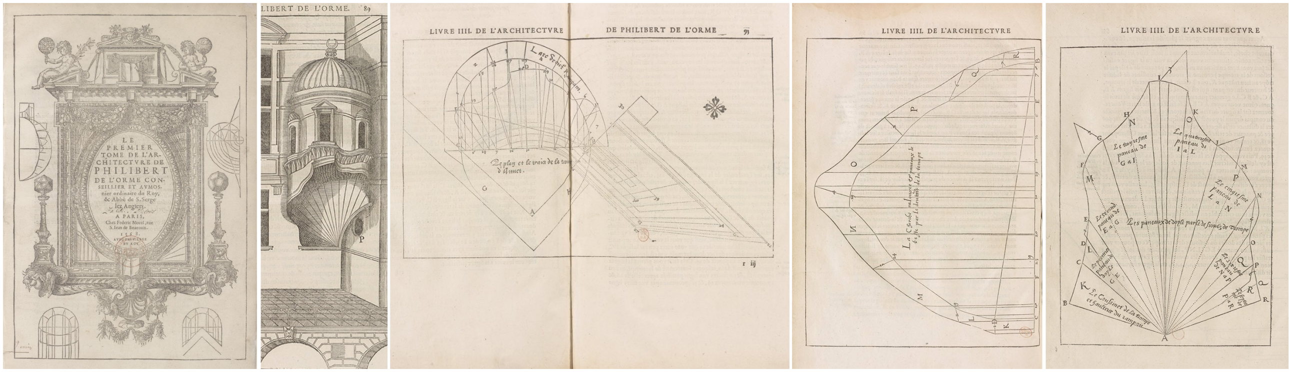


Fig. 7. Study in graphic statics of a dome structure [Ritter 1890, pl. 6, pp. 242, 243].



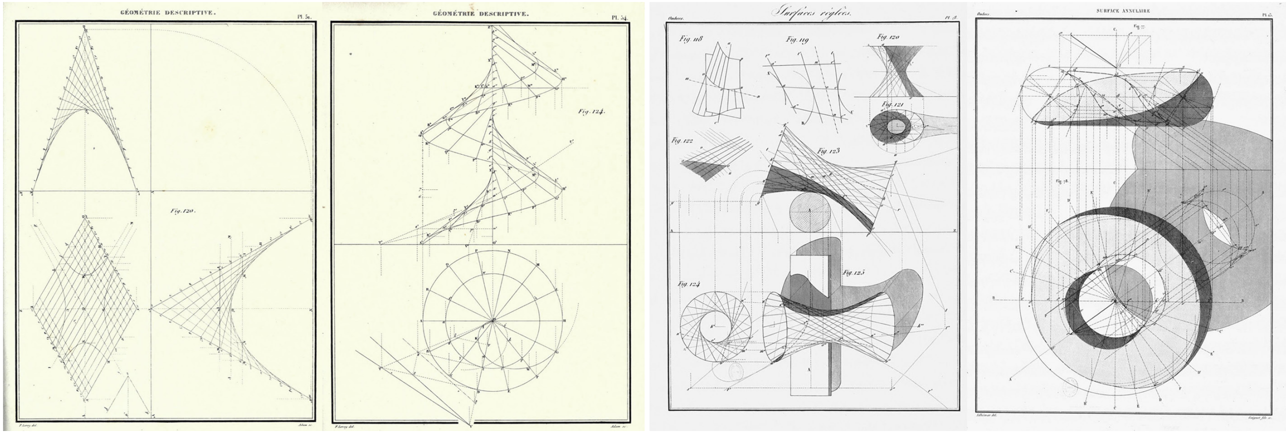


Fig. 8. Philibert Delorme, frontispiece of Le premier tome de l'architecture and traits géométriques of the trompe of the Château d'Anet (Delorme 1568, Frontispiece and ff. 89r, 92v, 93r, 94v, 95v).

Fig. 9. From left to right: Charles François Antoine Leroy, construction of a hyperbolic paraboloid and an oblique ruled helicoid (Leroy 1842, planches 51 and 54); Joseph Alphonse Adhémar, construction of shadows of notable surfaces (Adhémar 1866, planches 28 and 13).

Monge therefore recognized the cognitive capacity of the method of projections, and consequently of drawing, establishing it as the privileged tool of Descriptive Geometry. Unlike ancient geometry, which had supported constructive processes in various ways within specific areas of application, the emerging Descriptive Geometry, by the late eighteenth century, was taking shape in a novel and abstract form (fig. 9). In the introduction to his *Traité de géométrie descriptive* (1822), referring to the Leçons delivered by Monge at the École Normale in Paris in 1795, Jean-Nicolas-Pierre Hachette notes: "*Le recueil de ces leçons est le premier traité de géométrie descriptive dans lequel on a considéré cette science d'une manière abstraite, et indépendamment de ses applications.* […] *On y reconnaît cette faculté d'imagination qui lui faisait découvrir les propriétés de l'étendue figurée*" [Hachette 1822, p. X] [5]. The idea of a speculative science was fostered by Jean-Victor Poncelet in his *Traité des propriétés projectives* *des figures* (1822), to whom, according to Gino Loria, the revival of pure geometry is owed [Loria 1896, p. 24]. Whereas Monge's geometry sought the rigor and abstraction of an exact science devoted to the study of the geometric properties of lines and surfaces, with Poncelet's Projective Geometry, synthetic geometry emancipated itself from dependence on specific configurations, enhancing its capability for generalization through the exploration of the projective transformations of figures [Poncelet 1865, IX-XXXII].

Although theoretical abstraction had conferred scientific dignity on Descriptive Geometry, it remained strongly linked to its applications. The theoretical principles discussed had direct repercussions in architectural and engineering works, finding expression in Descriptive Geometry manuals in dedicated experimental chapters. Both a means of testing and validating speculative formulations and an autonomous corpus of Descriptive Geometry, these applications, in those years, acted as a driving force behind the development of innovative theories. The education offered at the École Polytechnique, and later at the polytechnic schools that followed, addressed the demands of a society marked by profound social and productive change, calling for theoretical abstraction to assume concrete form in the service of design across diverse fields of the arts and applied sciences [6] (figs. 10, 11). Within this context belong the contributions of students of Monge's school – among them Jean-Nicolas-Pierre Hachette and Charles Dupin– authors of authoritative treatises on theoretical Descriptive Geometry, as well as works devoted to geometry applied to engineering and the fine arts, such as the *Traité élémentaire des machines* [Hachette 1811] and the *Géométrie et méchanique des arts et métiers et des beaux-arts* [Dupin 1825] [7].

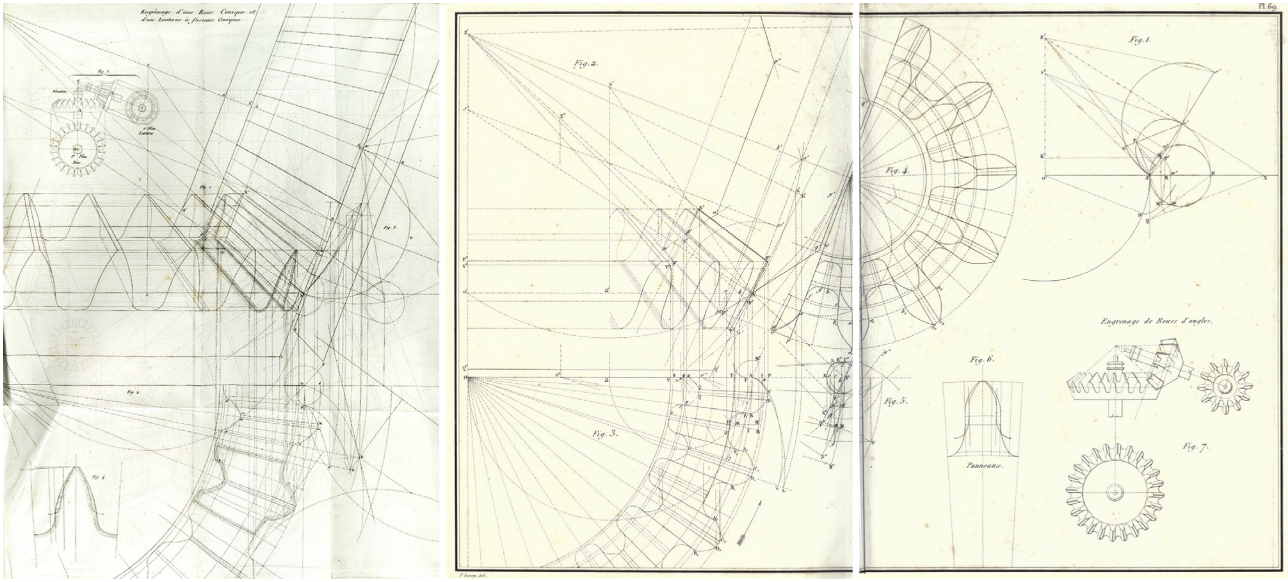
The synthetic method is therefore the tool through which Monge's school of Descriptive Geometry engages with figured space. Its scientific foundation is found in the second objective of this science, stated by Monge in the introductory program of his *Leçons*, which refers to a passage "from the known to the unknown", encapsulating and revealing the very essence of the heuristic value of drawing. This passage alludes to a process of knowledge in which drawing does not merely describe form, but becomes a tool for exploration and discovery, allowing the derivation of new properties of figures [Monge 1798, p. 2].

The cognitive dimension of drawing stems from the effectiveness of 'construction'. In his *Metodi matematici* published in 1935, Loria describes construction as a method of existence proof for figures: "*è noto che Euclide nei suoi Elementi non ragiona mai su una figura di cui non abbia prima insegnata la costruzione; questa funge, quindi, come dimostrazione dell'esistenza delle figure di cui erasi prima data la definizione*" [Loria 1935, p. 77] [8].

Whether mental or graphic, construction demonstrates the very existence of form, transforming drawing into a geometric, logical, and generative act. It is precisely the generative processes inherent in the act of constructing, and enacted through drawing, that enable the rigorous manipulation of form in space through visual languages, thereby granting Descriptive Geometry a central role in the morphogenetic control of design. If construction is the expression of a mental process that guides geometric operations in space, it simultaneously expresses a physical process leading to the material realization of form; in this sense, it acts as a bridge between idea, design, and built reality [Migliari 2012].

The idea of geometry as a generator of form, which had fueled nineteenth-century research in the domain of Descriptive Geometry, gradually drifted away from the generative processes of design over the course of the twentieth century, evolving into a didactic discipline that supports its graphic representation. Despite the innovative contributions made in the early decades of the century by mathematicians such as Otto Wilhelm Fiedler and Edmond Brhunes [Migliari 2009], to name but a few, the cognitive value of drawing was destined to be overshadowed by a predominantly abstract approach, marking the beginning of a gradual decline of Descriptive Geometry as a bridge between idea and material construction [9].

It is difficult to determine the reasons for this transformation, which was likely the combined effect of technological, cultural, and disciplinary changes that distanced design from the geometric processes of construction. At the end of the 1990s, in the conclusions of his *Épures d'architecture*, Joël Sakarovitch cites in this regard the words of Carlo Bourlet, the last holder of the chair of Descriptive Geometry at the Conservatoire national des arts et métiers in Paris, in 1907: "[*La géométrie descriptive*] *passa ainsi des mains des praticiens dans celles des théoriciens. Bientôt ceux-ci oubliant sa raison d'être, lui donnèrent une tournure de plus en plus dogmatique* […] *Les théoriciens nous défendent de lire dans l'espace* […] *et,*



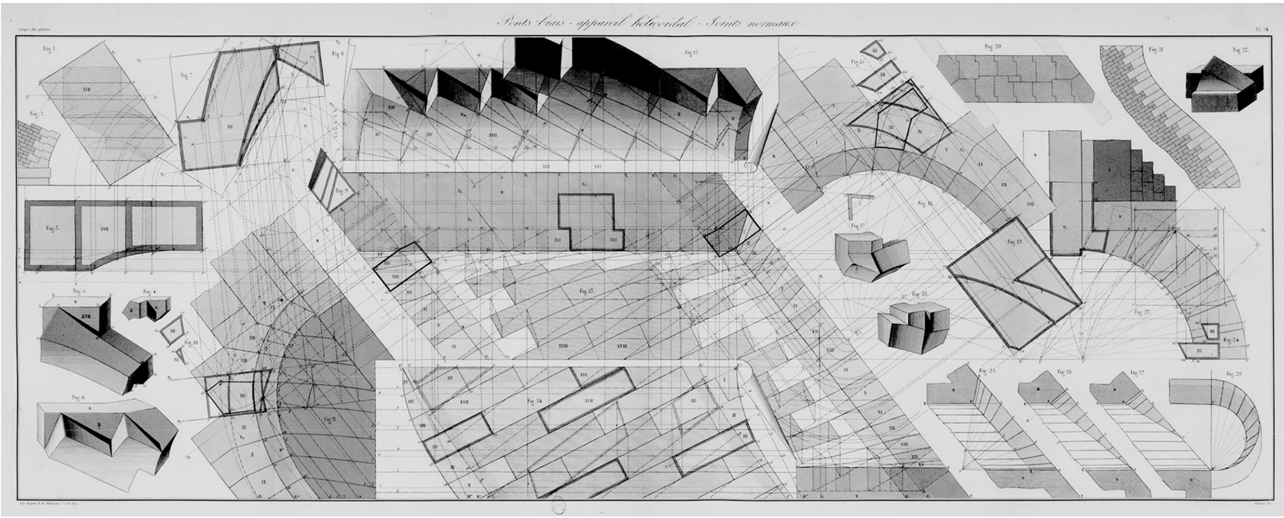


Fig. 10. Construction of bevel gears. Left: Hachette 1811, planche V 2^{me} chap.; right: Leroy 1842, planche 69.

Fig. 11. Joseph-Alphonse Adhémar, stereotomic apparatus for the construction of skew bridges (Adhémar 1856, planches 74 and 80).

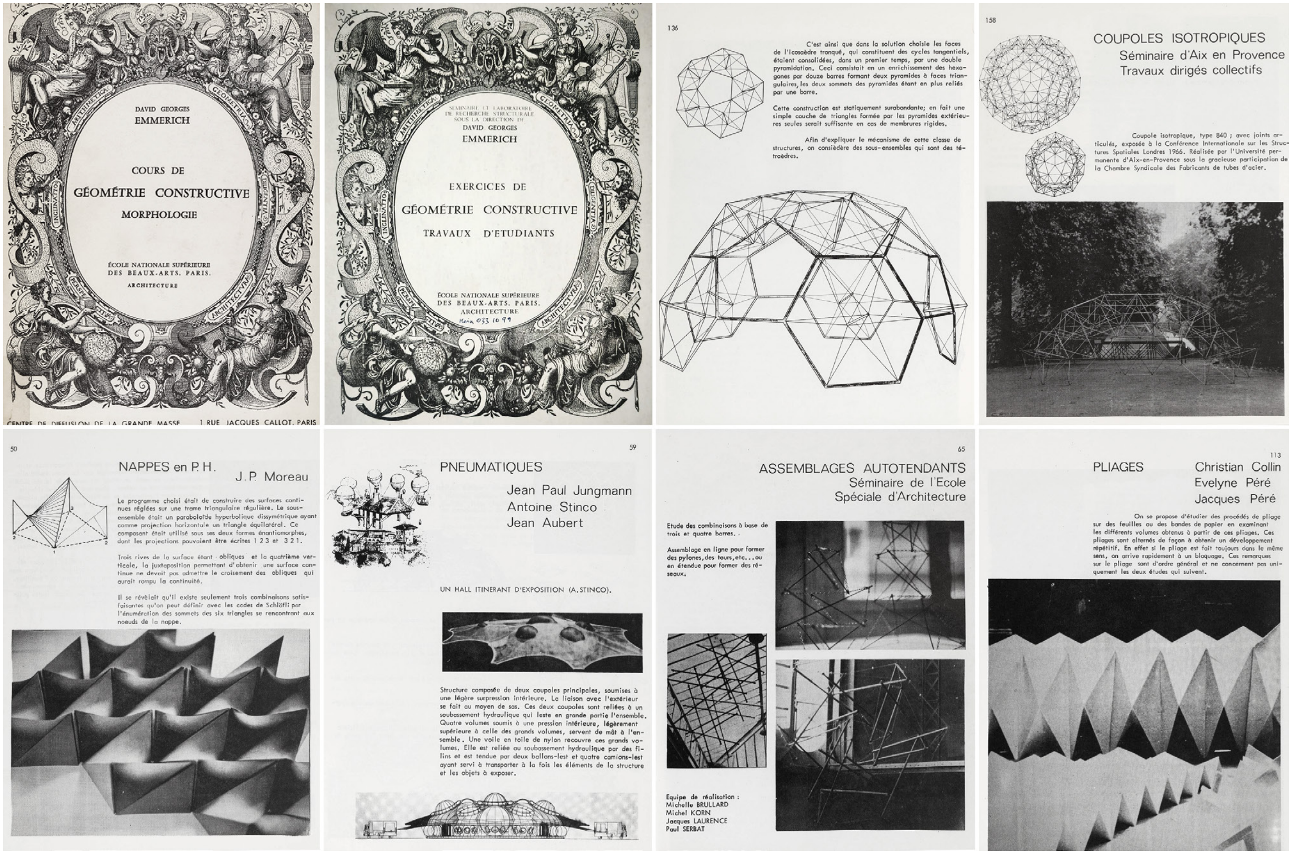


Fig. 12. David Georges Emmerich, cover of Cours de géométrie constructive, Morphologie (Emmerich 1969); cover of Exercices de géométrie constructive, Travaux d'étudiants, results of courses held at the École Nationale Supérieure des Beaux-Arts in Paris and a seminar conducted at the Université Permanente d'Aix-en-Provence (Emmerich 1970, pp. 50, 59, 65, 113, 136, 158).

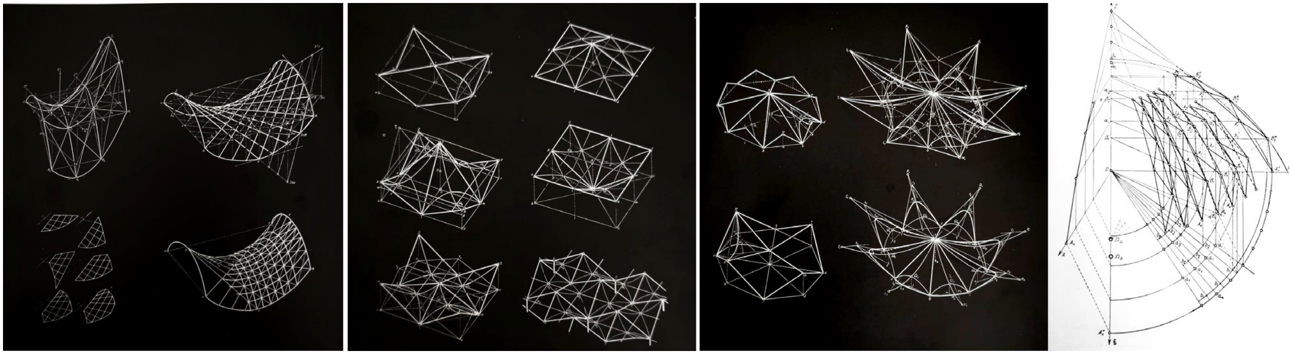


Fig. 13. Adrian Gheorghiu e Virgil Dragomir, representations of spatial structures, hyperbolic paraboloid, its aggregations and folded surfaces (Gheorghiu, Dragomir, 1971, pp. 42, 52, 55, 108).

pour justifier leurs prétensions, font exécuter, parfois à leurs élèves, des épures bizarres dont les données sont choisies à dessein de façon à rendre la vision impossible" [Sakarovitch 1998, p. 344] [10].

According to Bourlet, Descriptive Geometry should have been understood once again as the body of drawing applications aimed at solving execution problems in industry or providing accurate representations in the arts [Sakarovitch 1998, pp. 345, 346].

In the years following the First and especially the Second World War, the demands of reconstruction and the increased use of new building materials fostered significant advances in the application of geometry to design. Engineers such as Pier Luigi Nervi Eduardo Torroja, and Félix Candela used geometry as a tool for expressing architectural form, integrating structural calculation, geometry, and construction.

Starting from the mid-1950s, David Georges Emmerich, an architect, engineer, and professor of 'morphology' at the École des Beaux-Arts in Paris, promoted in France the idea of a *géométrie constructive*. Emmerich perceived a clear separation between architecture and geometric knowledge. He argued that "*L'architecture se mettait ainsi en dehors d'elle-même, en dehors de sa propre science*" [Emmerich 1969, p. 6] [11] and, in contrast, proposed the teaching of a 'science of forms' aimed at imagination, dimensioning, and the configuration of spatial structures, capable of classifying geometry, structures, and processes through the construction of physical models [Chassagnoux 2006] (fig. 12). In line with Emmerich's vision, but with a strong focus on the role of drawing in the generative processes of form, are the studies of a Romanian engineer and a Romanian architect, Virgil Dragomir and Adrian Gheorghiu, who, during the same period, focused on the study of structural geometries and their graphic representation, convinced that the genesis of spatial structures results from the synergistic action of architects and engineers, for whom geometry is the meeting point [12] [Gheorghiu, Dragomir 1978, p. 5] (fig. 13). These seemingly minor studies on structural morphology stand in continuity with the geometric experimentalism that, a few years earlier, had characterized the visionary works of Richard Buckminster Fuller, and appear in line with the pioneering form-finding experiments carried out in the same years by engineers such as Heinz Isler, Frei Otto, and Sergio Musmeci.

Generative physical models and graphic representations thus contributed to interdisciplinary research on architectural form, the former serving as tools for morphological experimentation and the latter as a means of visually representing the geometric properties of spatial structures.

The demonstrative capability of drawing, which had underpinned the scientific formulation of Descriptive Geometry and seems to have diminished in the following years, found new life in the early 2000s thanks to the spread of digital representation (fig. 14). Virtual exploration of three-dimensional space and the possibility of

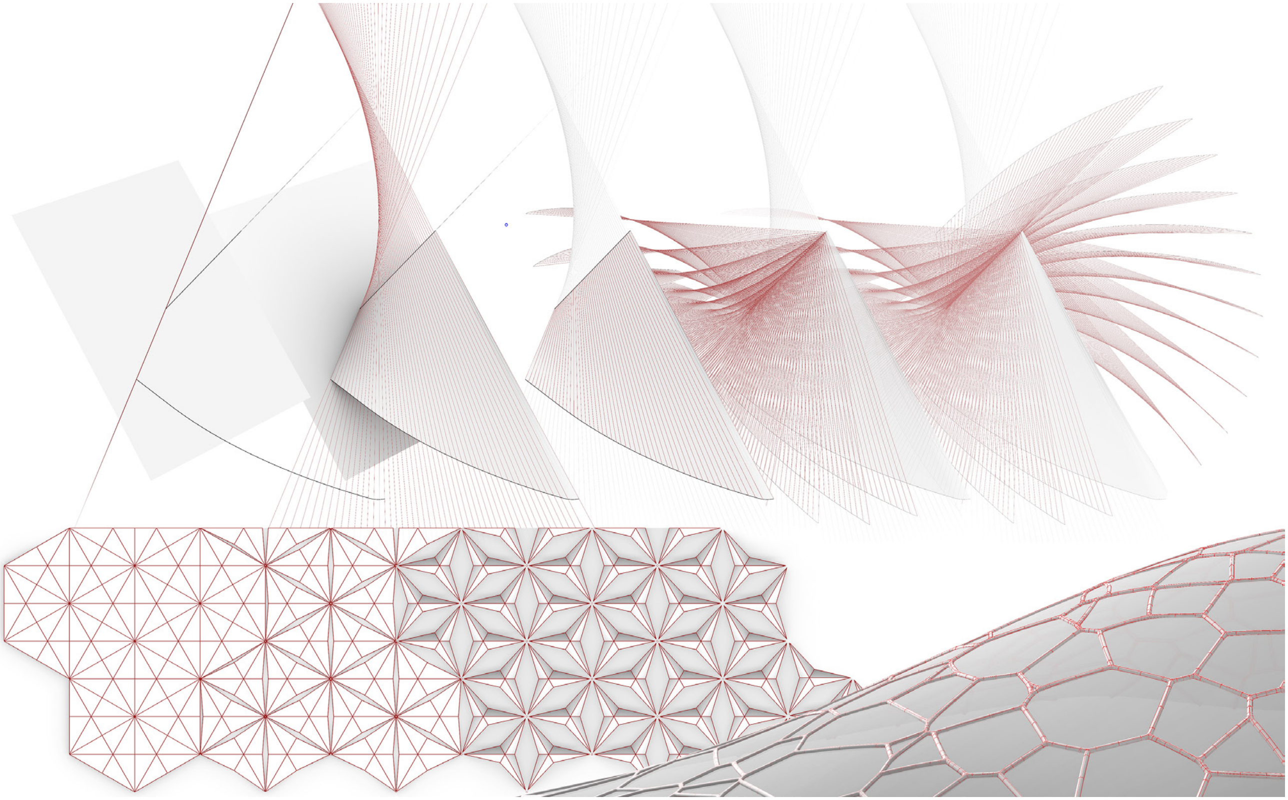


Fig. 14. Top: geometric genesis of a ruled surface with a director plane according to the Milwaukee Art Museum model by Santiago Calatrava, 2001; bottom: kinematically folded surfaces based on the Al Bahr Towers model in Abu Dhabi by Aedas, 2012; and tessellation of continuous surface using the Voronoi diagram (graphic elaboration by the authors).

using classes of skew curves and double curvature surfaces to derive the geometric properties of figures have restored renewed vigor to the construction and to the heuristic value of drawing, with significant repercussions in research and education [13].
During these same years, the development of digital representation tools and the possibility of working with an unprecedented and extensive repertoire of forms in architectural design fostered the development of Architectural Geometry, an experimental research field that places geometry at the center of the processes of generation and representation of form in architectural design [Pottman et al. 2007]. Through the tools of parametric design and computational modeling, Architectural Geometry explores freeform shapes, complex geometries, parametric structures, and problems of tessellation and discretization, integrating descriptive, differential, and computational geometric approaches.
Today, the languages of constructive geometry allow the aesthetics of design to emerge through the synergistic interaction of different disciplines, contributing to the creation of performance-efficient, constructively optimized, and morphologically innovative architectures. This virtuous synergy also involves Descriptive Geometry.
As a grammar of representation capable of translating space into models and as a science that studies the geometric properties of figures, Descriptive Geometry is, indeed, the only discipline that allows, both today and in the past, the dynamic and rigorous visual manipulation of form, enabling the exploration of design thought processes through the universal language of drawing.

Notes

[1] "Harmony of the parts in relation to a whole to which they are bound according to a precise number, delimitation and position" (translation by the authors).

[2] Pierre Boutroux, in *Les principes de l'analyse mathématique*, recounts the intent of certain geometers to elevate pure geometry to the level of the algebraic method by proposing a synthetic geometry capable of the same effectiveness and generality [Boutroux 1919, pp. 109-116].

[3] The origin of the name *géométrie descriptive* is discussed by Théodore Olivier in the introduction to the second edition of his *Cours de géométrie descriptive*, where he explains how Descriptive Geometry serves to depict what the mind sees and what it has seen, thereby revealing what is imagined as what is known [Olivier 1843, p. VIII]. As Gino Loria observes, Monge attributed a theoretical value to Descriptive Geometry arising from the way this science facilitated the conception and study of geometric figures, comparing its procedures to those of analysis and demonstrating their essential identity [Loria 1896, pp. 22, 23].

[4] "If I were to rewrite my work entitled *de l'analyse appliquée à la géométrie* […] I would write it in two columns: in the first, I would present the demonstrations through analysis; in the second, I would present the demonstrations through Descriptive Geometry, in other words, using the method of projections; and perhaps one would be surprised –he added– to see upon reading this work that the advantage would almost always lie with the second column, for the clarity of reasoning, the simplicity of the demonstrations, and the ease of applying the theorems obtained to the various works of engineers" (translation by the authors).

[5] "The collection of these lessons is the first treatise on Descriptive Geometry in which this science was considered in an abstract manner, independently of its applications. […] One can recognize therein that faculty of imagination which allowed it to discover the properties of figured space" (translation by the authors).

[6] For further information on the École Polytechnique see Cardone 1996.

[7] The influence of Descriptive Geometry on early 19th-century applications was mainly felt in gear theory, which responded to the needs of an emerging industrialization, and in stone stereotomy, which maintained continuity with a centuries-old tradition; for further details, see [Sakarovitch 1998, pp. 299-319].

[8] "It is well known that Euclid, in his *Elements*, never reasons about a figure without first having taught its construction; this, therefore, serves as a proof of the existence of the figures for which a definition had previously been given" (translation by the authors).

[9] In those years, Descriptive Geometry, consolidated and apparently complete, was still taught in the faculties of Mathematics, Architecture, and Engineering by mathematicians such as Gino Fano, Francesco Severi, Enrico Bompiani, and Luigi Campedelli, and, in the second half of the twentieth century, by Orseolo Fasolo and Ugo Saccardi, who carried the responsibility of keeping alive a centuries-old science that seemed exhausted [Migliari 2009, p. 19].

[10] "[Descriptive geometry] thus passes from the hands of practitioners into those of theorists. Soon, the latter, forgetting its very purpose, gave it an increasingly dogmatic character […] The theorists forbid us to read in space […] and, to justify their claims, sometimes have their students produce bizarre drawings whose data are deliberately chosen so as to make the visualization impossible" (translation by the authors). In his commentary on the quotation, Sakarovitch highlights how the abolition of the chair of Descriptive Geometry at the Conservatoire national des arts et métiers roughly coincided with the end

of the teaching of Descriptive Geometry at the École Polytechnique, and with the conclusion of the 'golden age' of this discipline in France: Sakarovitch 1998, p. 346.

[11] "Architecture thus placed itself outside of itself, outside its own science" (translation by the authors).

[12] In 1968, Adrian Gheorghiu and Virgil Dragomir published the volume entitled *La représentation des structures constructives*, a work that describes structural geometries through drawing. A review of the volume by Federico Fallavollita can be found in the *Readings/Rereadings* rubric of this issue of the journal *diségno*.

[13] In 2008, professors of Descriptive Geometry from numerous Italian universities, coordinated by Riccardo Migliari, promoted a *Manifesto* for the renewal of Descriptive Geometry, grounded in the rediscovery of the cognitive value of drawing through digital representation methods [Migliari et al. 2008].

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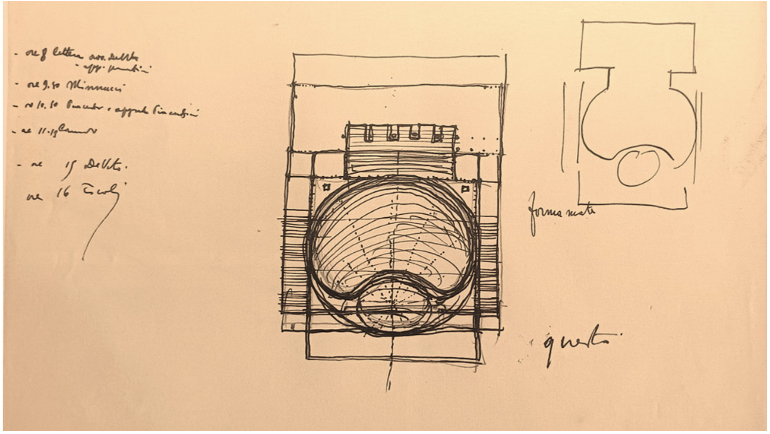
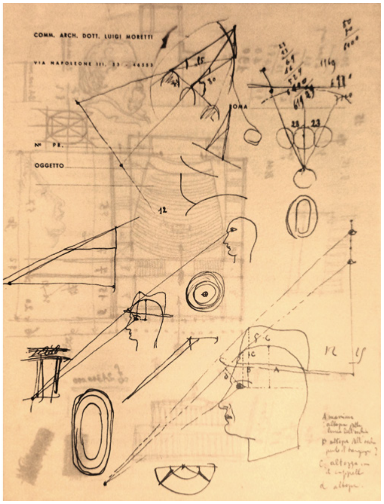
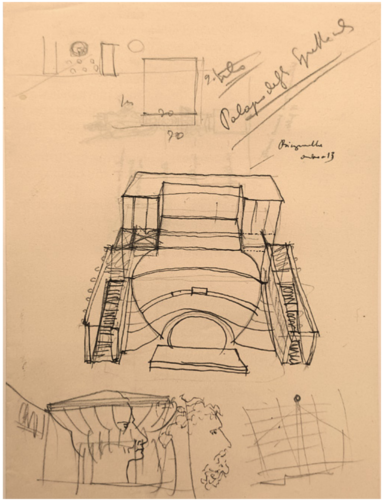
Some Preparatory Studies for the Imperial Theatre at E42

Luigi Walter Moretti







The Parameters of the Figure: Drawing as a Diagram of Figural Forces

Fabrizio Gay

The drawings preserved in the Moretti-Magnifico Archive reveal an approach to architectural design based both on the evocation of mythical buildings and on the calculation of precise functional parameters. The three preparatory sketches for the Imperial Theatre at E42, made by Luigi Moretti in 1937 and published here, are merely rough drafts of a solution later discarded: private notes, rapid and fragmentary, yet revealing of Moretti's method, which uses drawing as a diagram of forces to record the interweaving of structural, spatial, and perceptual tensions within which the project develops.
In particular, the sketches on the letterhead sheet reflecting on visual angles within the theatre cavea seem to anticipate the principles of 'parametric architecture' that Moretti would fully develop in 1960 at the *XII Triennale di Milano*, where curves of 'equal visual appetibility' defined the (almost naturalistic) shapes of 'ideal cavea' surfaces depending on various sporting events, specifically calculated according to geometric parameters of optimal visibility for every spectator.
The three 1937 sketches certainly do not outline the extremely clear teleonomic shapes and fully optimized caveas of 1960. They are freehand notes in which trajectories of force lines attempt to define an 'architectural figure', seeking to articulate some aspect of a parametric structuring that embraces both functional aspects and iconic or symbolic evocations. Even though these sketches outline a design solution later abandoned, they reveal figurative pregnancies (archaeological figures and modern issues of structure, visibility, and spatial organization) meant to measure the geometric and perceptual reasons of the cavea. With these diagrams, Moretti attempts to

This article was written upon invitation to frame the topic, not submitted to anonymous review, published under the editorial director's responsibility.

translate an 'ideal structure' into signs: a system of efficient relations between constructive constraints and evoked images, balancing building tradition and technical innovation, abstraction and figurality, construction and the sculptural plasticity of architecture.
This kind of diagram belongs to the broad genre of morphological figuration that follows, above all, a Renaissance tradition founded on Drawing understood as a tool to reveal the *Eidos* of things: the internal laws that define their form and the morphogenetic forces that generate them: namely, i) mereological relations (of a plastic or abstract nature, between parts and whole) and ii) analogies (of an iconic or figurative nature) among different forms. In this sense, Drawing does not merely depict but reveals the constitutive principles of artefacts, understood as aesthetic and structured organisms.
Moretti's sketches, however, are not among the most accomplished examples of this techno-artistic genre of morphological representation. The most renowned emblems of this 'morphological' genre are the anatomical and constructive drawings of Leonardo, Michelangelo, Borromini, Goethe, D'Arcy Thompson, and Haeckel, which have become exempla of visual synthesis describing the generative mechanisms of the depicted forms and structures: true icons in the history of scientific and artistic representation with a profound and lasting cultural impact.
What matters, in Moretti's case, is not the visual appeal of his drawings; rather, it is the comparison between the qualities of his drawing and those of his built architecture. From this point of view, the theoretical Moretti clearly expresses his adherence to the tradition of 'morphology' introduced by Johann Wolfgang Goethe [Goethe 1817-1824] and developed by D'Arcy Wentworth Thompson in *On Growth and Form* [1917]. In his method of analyzing and prefiguring architectural artifacts, expounded between 1950 and 1953 in the seven issues of the journal *Spazio, Rassegna delle Arti e dell'Architettura*, in the exhibition on parametric architecture at the *XII Triennale di Milano* (1960), and in the essays *Strutture di insiemi* [Moretti 1963] and *Le serie di strutture generalizzate di Borromini* [Moretti 1964], two fundamental bibliographical references emerge: i) *Search for Form* by Eliel Saarinen [1948] and ii) *Aspects of Form*, the famous volume edited by Lancelot Law Whyte [1951], which brings together interdisciplinary contributions to the science of form, including Rudolf Arnheim's work on the psychology of visual perception and Konrad Lorenz's on the ethology of visual perception. In the second essay that Whyte published in that volume, he introduces the concept of 'structure as form', a concept Moretti adopts verbatim in his similarly titled essay published (originally in French) in 1954 [Moretti 1954].
In *Structure comme forme* Moretti develops a fundamental distinction between practical structure (understood as the constructive and material component of architecture) and 'ideal structure' (the conceptual and spatial vision constituting its intellectual and poetic expression).
The way Moretti defines 'ideal structure' refers to a specific aspect of contemporary scientific morphology: the study of the 'qualities of forms'.
The 'expressive qualities of forms' are the properties of objects or events that convey perceptual, emotional, or symbolic meanings, at least in the sense understood in the phenomenological psychology of perception: from *Gestalt* theory to the early cognitive studies of naïve physics.
Moretti assimilates and reworks key concepts from contemporary psychological research to define an architecture that operates on three interconnected levels:

- rational (structure), adopting *Gestalt* principles of perceptual organization, particularly the theory of good form, reinterpreting them dynamically and sequentially according to Auguste Choisy's teaching on architectural space as a temporal experience;
- perceptual (light and space), integrating early theories of cognitive psychology (particularly the idea of an active process in constructing perceptual reality) to articulate the spatial sequentiality of built environments, anticipating themes that would become central to architectural phenomenology;
- symbolic (archetypes), investigating cultural stereotypes (according to contemporary social psychology) in search of universal figures, in an attempt to reconcile historical specificity with the timeless value of form.

Moretti's originality also lies in relating these psychological dimensions of form to the postwar developments of operational research in mathematics, originally created to solve logistical and strategic problems and already applied to architecture to optimize shapes and structures through rule-based methods. Between the 1950s and 1970s, mathematical modeling provided generative tools that anticipated today's computational design, in which algorithms and parameters guide form. In this context, the diagram becomes the common language of an epistemological transition: from the building as a finished object to construction as a multi-dimensional morphogenetic system. Christopher Alexander gained great influence with *Notes on the Synthesis of Form* [1964], theorizing design through hierarchies of diagrams of functional requirements and introducing 'Tree diagrams' and 'Force diagrams' to map conflicts between social and structural demands. During the same period, Frei Otto, Buckminster Fuller, and Sergio Musmeci developed radical morphogenetic methods in which form emerges from physical laws, systemic geometries, or tensile equilibria rather than from compositional arbitrariness.

Otto, for example, used physical models –soap bubbles or stretched nets– to generate minimally energetic forms, later tracing diagrams 'force flow diagrams') to visualize load paths and points of tension on membranes and shells. This method, based on observing natural tensile equilibria, has deep historical roots. Already Robert Hooke (17th century) had demonstrated that the shape of a perfect compression arch corresponds to the configuration of a hanging chain, a principle later formalized by Johann Bernoulli and Giovanni Poleni and, in the 19th century, experimented with by Antoni Gaudí through inverted funicular models to determine the geometries of the Sagrada Família. In the twentieth century, Heinz Isler and Musmeci experimented respectively with deformed fabrics and elastic rubber models to optimize shells and bridges.

In the 1930s and 1940s, the experimental study of force configurations through stressed physical models was practiced in Italy. While designing Project A for the Palazzo del Littorio competition (1934) –in which Moretti also participated– Giuseppe Terragni, Pietro Lingeri, and Luigi Vietti employed transparent celluloid sheets to visualize isostatic lines and determine the optimal arrangement of metal staples within the large wall of Project A. Similarly, Pier Luigi Nervi used comparable methods to optimize reinforced concrete structures based on the actual distribution of forces, while Eduardo Torroja in Spain experimented with plaster models for his thin shells. These techniques, based on direct analysis of tensions, share the idea that structural form derives from the equilibrium of forces, anticipating modern approaches to form-finding.

Yet Moretti's aesthetics differ radically from the engineering approaches of Fuller, Otto, and Musmeci. Whereas these pursue a teleonomic logic in which form is primarily determined by physical objectives, Moretti integrates a deeply figural dimension, derived from Greek and Baroque architecture, into a system in which structure, perception and symbol merge. His drawings contain not only the early traces of parametric architecture but also the evocation of archetypes such as the Pergamon Altar (2nd century B.C.), in a summit-like and acropolis-like structure where sculpture and architecture fuse into a spatial and narrative system. It is a figurality that rejects easy iconisms, as suggested by the annotation "*forma nuda*" in one of the sketches, where Moretti tends toward a structure stripped of ornament, reduced to its 'figural' essence.

The term 'figural' originates in Husserlian phenomenology, where it denotes the moment in which a multiplicity presents itself as a perceptual unity before being classified. In Freudian theory, it designates the condensation of different meanings into a single form. Jean-François Lyotard, in *Discours, figure* [1971], defines it as that level of imagination in which the object is neither yet figure nor pure form, but a diagram of pregnancies that may propagate into semantically distant saliences. For Moretti, the figural is the structure of forces, tensions, and pregnancies that precedes the categorization into 'abstract' or 'figurative': it is the emergence of form as a field of expressive potentialities, even before it appears as a recognizable (iconic) object or pure geometry (plastic). Similarly, in Freudian dream theory the 'figural' denotes the way in which different meanings and affordances condense into the same perceived form (e.g., a staircase may 'express' ascent, effort, mystery etc.).

Moretti's drawings sometimes exemplify precisely a graphic technique of 'condensation' (in the Freudian sense): they present an idea more than represent it; they open a parametric inquiry that seeks to reveal the generative forces of form. His originality lies in uniting morphological tradition, psychology of perception, and operational mathematical research to create an architecture that transcends the dichotomy between abstract and figurative, proposing a mythological (figural) vision of architectural form.

This raises a broad question: to what extent can contemporary digital technologies, though capable of unprecedented formal optimization, capture the figural complexity that Moretti explored through traditional graphic drawing, with gestures integrating morphological tradition, perception, and symbol into a meaningful unity? How, today, can we explore that same complexity within an ecosystem of Artificial Drawing, where generative intelligence not only parametrizes forms but redefines the very parameters of meaning –between cultural memory, perceptual experience, and invention– in a co-authorial dynamic of interaction between human design and algorithmic elaboration?

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THE REVEALED STRUCTURE.
DRAWING BETWEEN CONSTRUCTION AND FORM

Structures Made Visible.
Drawing as Constructive Revelation

Idea, Form, and Structure: Frank Lloyd Wright's *Archeseum*

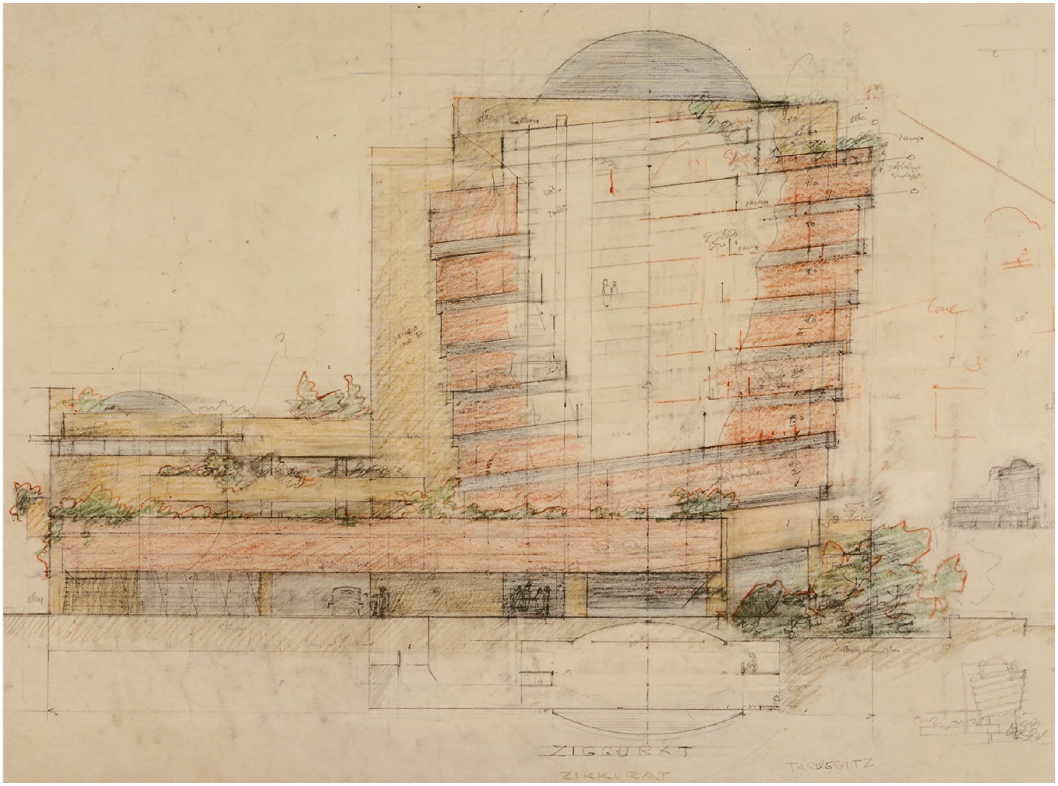
Cosimo Monteleone

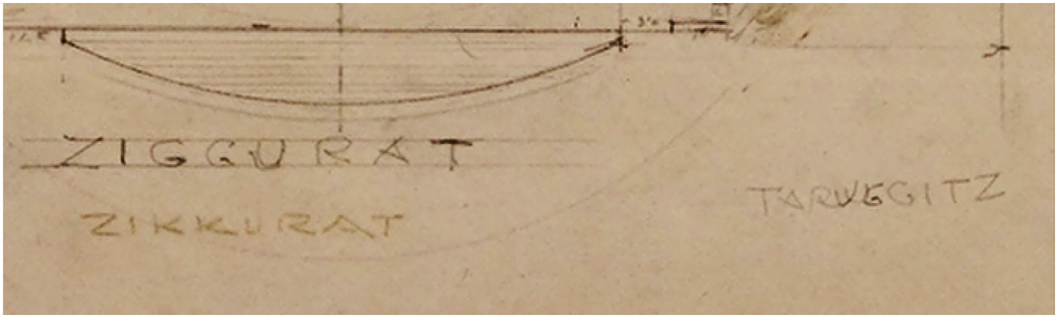
Introduction

The design of the Guggenheim Museum had a long and troubled history. The building was strongly opposed by supporters of the International Style due to its revolutionary and innovative nature [1], but Frank Lloyd Wright strenuously defended his idea, presenting it to public opinion as the only example of Organic Architecture [2] in New York [Dal Co 2004, p. 27].
The initial planning constraints were roughly the following: having to build no further than Midtown, the building would have belonged to the rigorous New York Hippodamian grid, so, in spite of himself, Wright was forced to fall back on the idea of a compact and vertical museum. He had already developed the main characteristics of his project [Ballon 2009, pp. 19-37] even before deciding on a location on the Upper East Side facing Fifth Avenue on a lot between 88th and 89th Street. The decision to organize the museum around two nuclei, a larger one, the Archeseum, the majestic exhibition space, and a smaller one, called the Monitor Building, the latter created to house the offices, came after very rapid steps. In fact, at the end of 1943, in the thick correspondence addressed to Solomon Robert Guggenheim, the client, and to Hilla von Rebay, the first curator of the museum, the architect's enthusiasm immediately became clear [Brooks Pfeiffer 1986, p. 25].

This article was written upon invitation to frame the topic, not submitted to anonymous review, published under the editorial director's responsibility.

Fig. 1. F.Ll. Wright, Guggenheim Museum: drawing, 1943, code 4305014 (courtesy of Avery Library, Columbia University, New York).
Fig. 2. F.Ll. Wright, Guggenheim Museum: drawing, 1943 code 4305014, detail (courtesy of Avery Library, Columbia University, New York).



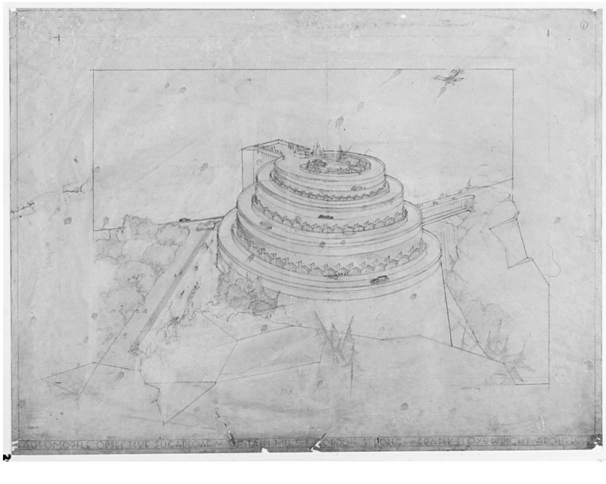


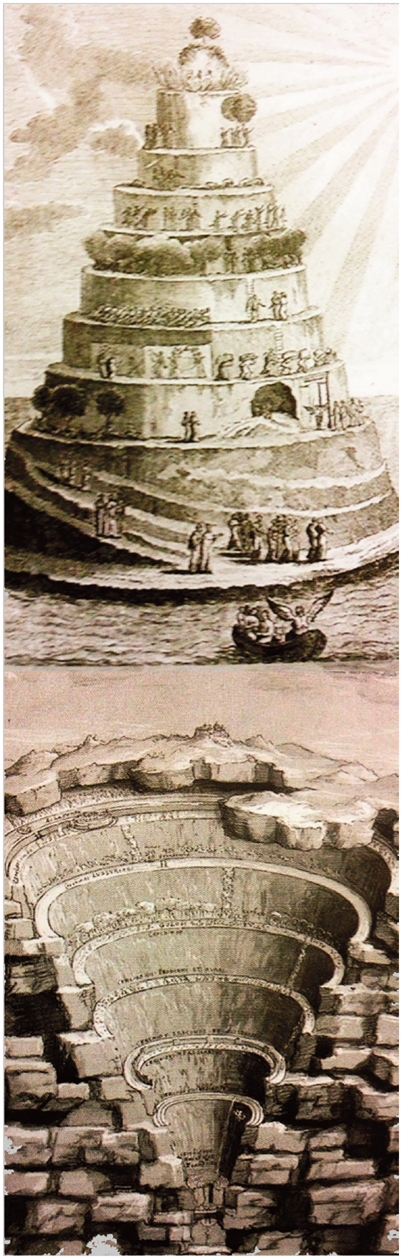
Idea and form

A drawing, performed during that period of intense fervor, shows the architect's complete vision (fig. 1), quickly expressed through the representation of the main facade facing Fifth Avenue. In the large exhibition hall, the nerve center and complex hub of the building, Wright presents the observer with a dual vision. The strokes of color, which entirely characterize the graphic rendering of the facade, break toward the center, following the contour of a wavy line, to make room for a thin pencil line. In this way, the architect simultaneously depicted both the interior section and the exterior elevation.
A small note in the drawing clarifies how the author did not miss the semantic and formal relationship of his idea for the Guggenheim Museum with an archetype of biblical architecture, noted in the words written at the bottom: "Ziggurat" and "Zikkurat" later transformed into "Taruggitz" (fig. 2). The inversion of the letters in Wright's neologism clearly testifies the desire to invert the archetypal form of the ziggurat [Carranza 2009, p. 94], usually composed of recessed steps but transformed in the Guggenheim into an inverted truncated cone. The inspiration provided by this important drawing opens the possibility of tracing, through analysis of form and structure, the genesis of the architect's mental journey through the labyrinthine meanders of his thought.
If, in general, retracing the struggle behind the design concept means identifying and highlighting the causes that infused form and meaning into a building, this backwards journey is even more desirable for the Guggenheim Museum, since its original idea has retained its character unchanged for more than a decade, despite the negative opinion of numerous and illustrious colleagues of Wright, which, in some ways, was also followed by the irony of public opinion [Dal Co 2004, pp. 27, 28].
The importance of this drawing, accompanied by a simple written note reminiscent of childhood anagrammatic puns, did not escape Francesco Venezia, who expressed himself in this way: "What may appear to be a joke, a funny pause in the process of conceiving the project, reflects an important change […]. The primitive form of the ziggurat, an original form, biblical and Mesopotamian –the mass that diminishes as the height increases– changes, with the elementary immediacy of the mirror reversal, into an absolutely new form: the mass now grows upwards. The Guggenheim is born, unmistakably!" [Venezia 2012, p. 36].

The initial idea wasn't so immediate; the early stages of its birth are rooted in a long process of development, dating back to the mid-1920s; during this period, the archetypal theme of the ziggurat had already surfaced in the American architect's memory with the project entitled Gordon Strong Automobile Objective and Planetarium (fig. 3). To better understand how these aspects are also linked to the New York museum, it should be noted that only the development of concrete and the subsequent revolution sparked in the field of construction by reinforced concrete offered Wright the opportunity to reconfigure the forms sedimented in his childhood, to overturn an archetype and transform the Guggenheim Museum into 'taruggitz'.
In the United States, one of the most widespread uses of reinforced concrete, composed of cement and iron bars, was the construction of helicoid ramps for the first urban parking lots. These surfaces allowed cars to be driven from the ground floor to the roof, and we know that Wright immediately looked with interest at this type of solution, because he associated the continuity of the material with experiential continuity. The fact that reinforced concrete and its innovative uses for the creation of ramps were a source of inspiration for the American architect is evidenced by some writings jotted down years after a visit to the Ford Motor Company in Detroit, a building designed and built

Fig. 3. F.L. Wright, Gordon Strong Automobile Objective and Planetarium, drawing, 1924, code 2505053 (courtesy of Avery Library, Columbia University, New York).





by Albert Kahn, for whom Wright had always had great respect [Brooks Pfeiffer 1992, p. 55].
Thus, long before the Guggenheim Museum was commissioned, after having glimpsed the possibilities introduced by reinforced concrete, Wright was inventing ways to shape the material beyond appearances and beyond the known. Essentially, he set out to find geometric configurations that would allow him to express the movement and dynamism of space with a fluid and plastic gesture. Regarding the Guggenheim Museum, Francesco Venezia astutely points out that, during his formative years, Wright had already witnessed the representation of the inversion of a ziggurat in 'taruggitz', leafing through the pages of the translation of Dante Alighieri's Divine Comedy, illustrated by the poet and artist William Blake [Venezia 2012, pp. 48-60].
Wright had a particular predilection for Blake [Monteleone 2013, p. 28], but there is also irrefutable evidence demonstrating a profound knowledge of what can be considered the magnum opus of Italian literature. The connection is offered by Victor Hugo's Notre-Dame de Paris, which Wright had discovered in his youth. The passage in which the French writer announces the advent of a great architect of genius who would play the same founding role in the twentieth century that Dante had in the thirteenth [Hugo 1831, p. 207] certainly did not leave Wright indifferent [Monteleone 2013, p. 19]. Indeed, given the American architect's notoriously overblown ego, there is no doubt that he considered the celebrated French writer's prophecy a premonitory sign of his own personal contribution to the renewal of architecture. This consideration would have led to the conviction that his work had undertaken a marvelous feat, comparable to that accomplished in literature, some seven centuries earlier, by Dante Alighieri. Wright, therefore, may have discerned in Blake's images, which depicted the formation of purgatory as a result of the excavation material from the hell (fig. 4), the seed of the inversion that characterizes the anagrammatic play on the word ziggurat in 'taruggitz', proudly noted in the margin of his study drawing, to indelibly mark the profound formal revolution of the Archeseum.
As proof of the validity of these literary references it is worth considering a passage from a speech by Wright, given at a time when there was no suspicion, which reveals his faith in the idea that only new technologies could trigger a revolution in architecture, comparable to that sparked in

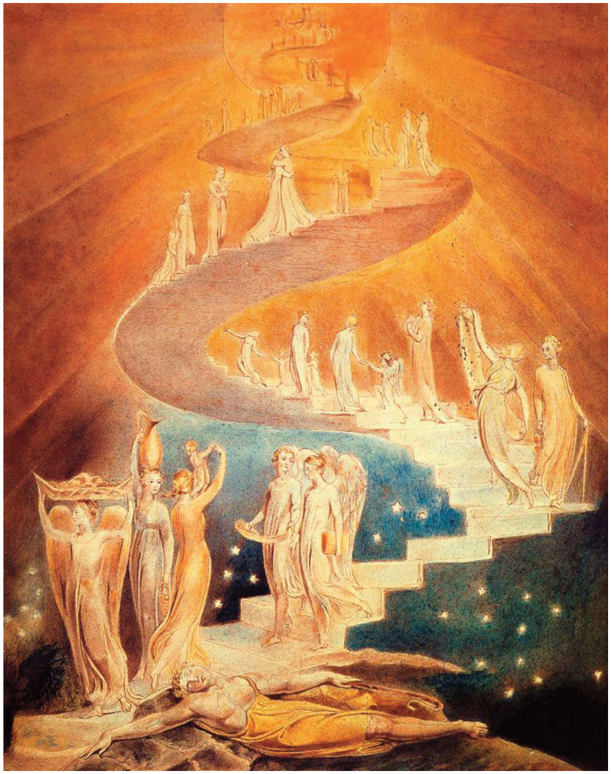
Fig. 4. W. Blake, Formation of Purgatory and Paradise [Blake 1838, p. 11].

the world of literature by the most illustrious exponents of all cultures. According to the American architect, the new materials used in human machines had characterized the physical essence of our time, distinguishing it from previous centuries [Wright 1901, p. 80].
But there is another illustration by Blake, which, in an even more evocative way, could have stimulated Wright's fervent imagination in the development of a helicoid ramp for his museum. This image, in some respects, possesses the same miraculous quality as the suspension effect embodied in the Archeseum; it is a representation entitled *Jacob's ladder* and describes Jacob's dream vision (fig. 5), contained in the book of *Genesis* [Blake 1794]. The episode in question is the following: Jacob, after a long journey on the road to Charan, decides to camp in an unspecified place. During the night he dreamed of a ladder resting on the earth, whose top reached the sky, crowded with angels ascending and descending.
How can we not connect William Blake's elegant interpretation of Jacob's dream, centered on the design of a ladder that stands on its own until it disappears into the clouds, with the exhibition at the Guggenheim Museum?
But once we've established that this miraculous effect was meticulously sought in the *Archeseum*, it's worth analyzing the elements that made the architecture possible.

Form and structure

Passing from idea to construction, the Archeseum gathers and fuses the following compositional elements into a dynamic and elastic structural unit: the helicoid ramp, the twelve radial structural partitions, and the dome. Wright's tectonic solution undoubtedly seems aiming at the expressive quality of the interior space, relying on the stunning effect created by the helicoid ramp, apparently solved without pillars and beams, which would have evidently compromised its continuous and enveloping character. From a technical and technological standpoint, the so-called 'helicoid elastic beam' had already been the subject of in-depth speculation at the beginning of the 20th century [Markus 1914] and, as we have also had occasion to highlight, repeatedly applied in the automotive industry to solve the parking problem in increasingly congested American cities.
In addition to the undoubted practicality of being able to connect levels at different heights without interrupting the motion, the particular spatial configuration of a helicoid beam implies a further advantage from a static and structural point of view, since the contributions triggered by the normal and shear stresses generate a redistribution of the loads, compensating for the values of the torsional moment and producing overall stresses that are significantly lower than those that would occur with overlapping ring beams [Belluzzi 1942, p. 253].
From a structural point of view, the ramp of the Guggenheim Museum behaves exactly like an elastic beam with a helicoid development but, even if the structure apparently uninterruptedly envelops the space of the central cavity, it is necessary to point out that the continuous growth of the helicoid surface occurs only for 270 degrees of the base circle, first projection of the helicoid, while the remaining

Fig. 5. W. Blake, Jacob's ladder [Blake 1838, p. 16.].



90 degrees, corresponding to the stairs and elevators, interrupt the development of the ramp, replacing it with a classic system of overlapping levels supported by pillars (fig. 6). The entire helical path, from the first level to the top, intersecting in the ascent with the twelve radial partitions, collaborates closely with the latter, which are entrusted with a dual static task: that of supporting the upper spirals of the ramp and at the same time stabilizing the lower ones, generating an overall union which, exploiting the radial pseudo-symmetry of the structure, proves to be considerably solid and firm [Trombetti 2007, p. 50].
From a static point of view, what raises the greatest doubts is the theory of triangular partitions with an inverted shape. In fact, if these vertical elements served throughout their entire development to support the normal stress triggered by the helicoid ramp, then, as they approached the ground, they would have to present an increasing cross-section to adequately cope with the loads accumulating from above. However, the opposite occurs, so much so that, at the base of the building, the cross-section of the partitions is characterized by a practically inconsistent size (fig. 7).
Interestingly, from the first to the third level, the radial partitions, and consequently the helicoid ramp, are surrounded by a cylindrical band, whose static behavior can be likened to that of the drum of a dom. This external band serves as a substitute for the twelve triangular elements in the role of load-bearing structure for the vertical loads. The radial partitions, therefore, from the first to the third level rest on the surrounding cylinder for the entire 270-degree arc, while they hover as true, independent load-bearing elements from the fourth level up to the summit (fig. 8).
The inseparable collaboration between the external cylindrical belt and the radial partitions emerges from the words of Tomaso Trombetti, who conducted an in-depth study of the load distribution in the *Archeseum*: "Assuming that the partitions have a vertical load-bearing function, one can therefore imagine a progressive transfer of vertical forces from the partitions themselves to the drum at the first three floors of the building. This transmission of vertical forces to the drum also allows for the uniform distribution of the vertical forces discharged from the structure to the ground at the base ring, thus improving the functioning of the foundation system as well" [Trombetti 2007, p. 52].
The technical solution implemented by Wright evidently has a very specific intent from a figurative and formal point of view. In fact, the use of such a complex load-bearing structure, consisting of the collaboration between the twelve inverted triangular elements and the cylindrical band that surrounds them at the first levels of the building, allowed their designer to create a sort of optical illusion that makes the helicoid ramp appear as if it were suspended throughout the volume of the central cavity, in

Fig. 6. Plan of the Archeseum. The image shows the 270-degree helical ramp and the 90° cantilevered floor (graphic elaboration by the author).

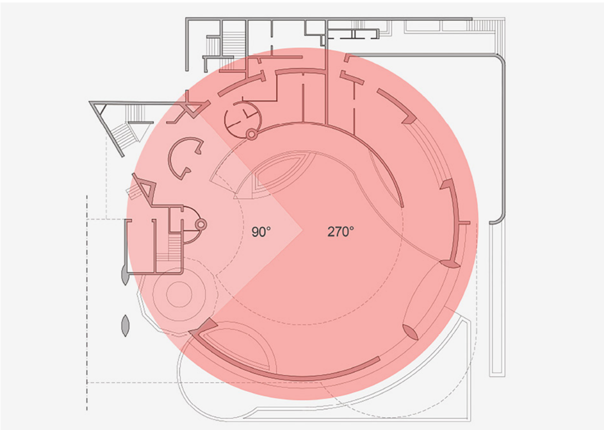
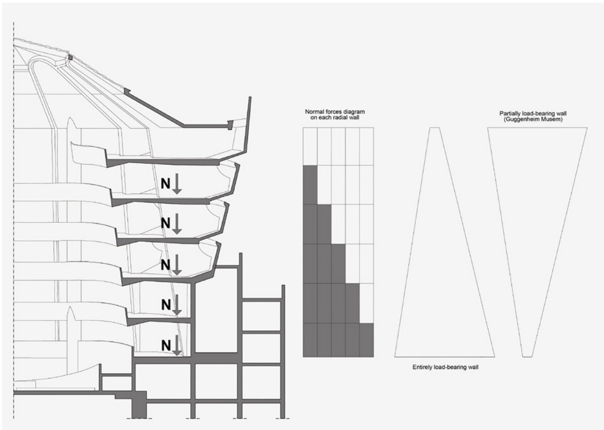


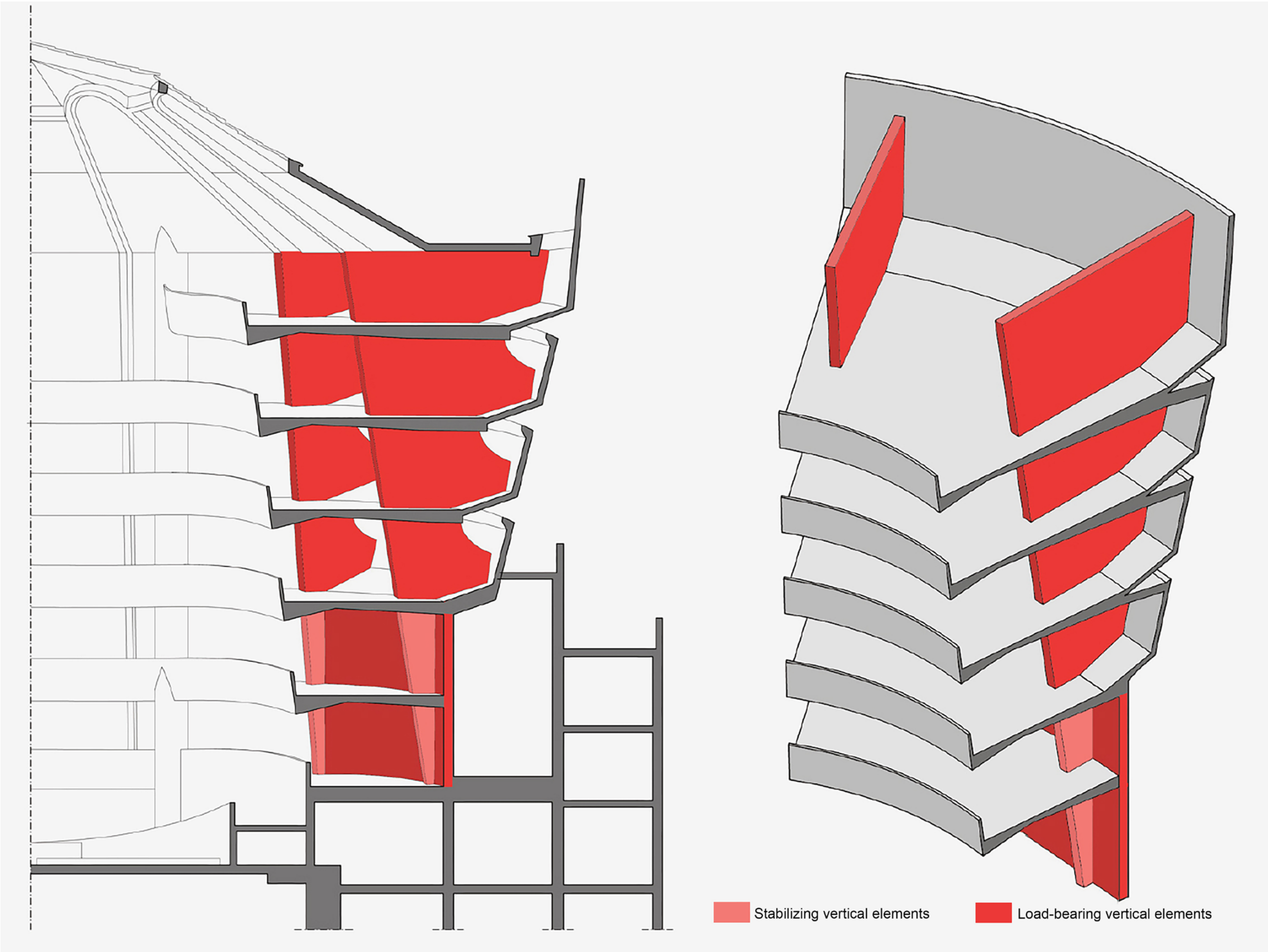
Fig. 7. Radial walls of the Archeseum: analysis of normal forces (graphic elaboration by the author).



the act of self-supporting. In addition to the partitions, the helicoid ramp is also subjected to specific stresses. In fact, being embedded every 30 degrees to a pair of triangular supports, it has a longitudinal section subject to a bending moment, caused by the presence of the cantilevers that increase in size towards the inside, as one ascends to the top [Trombetti 2007, p. 53].

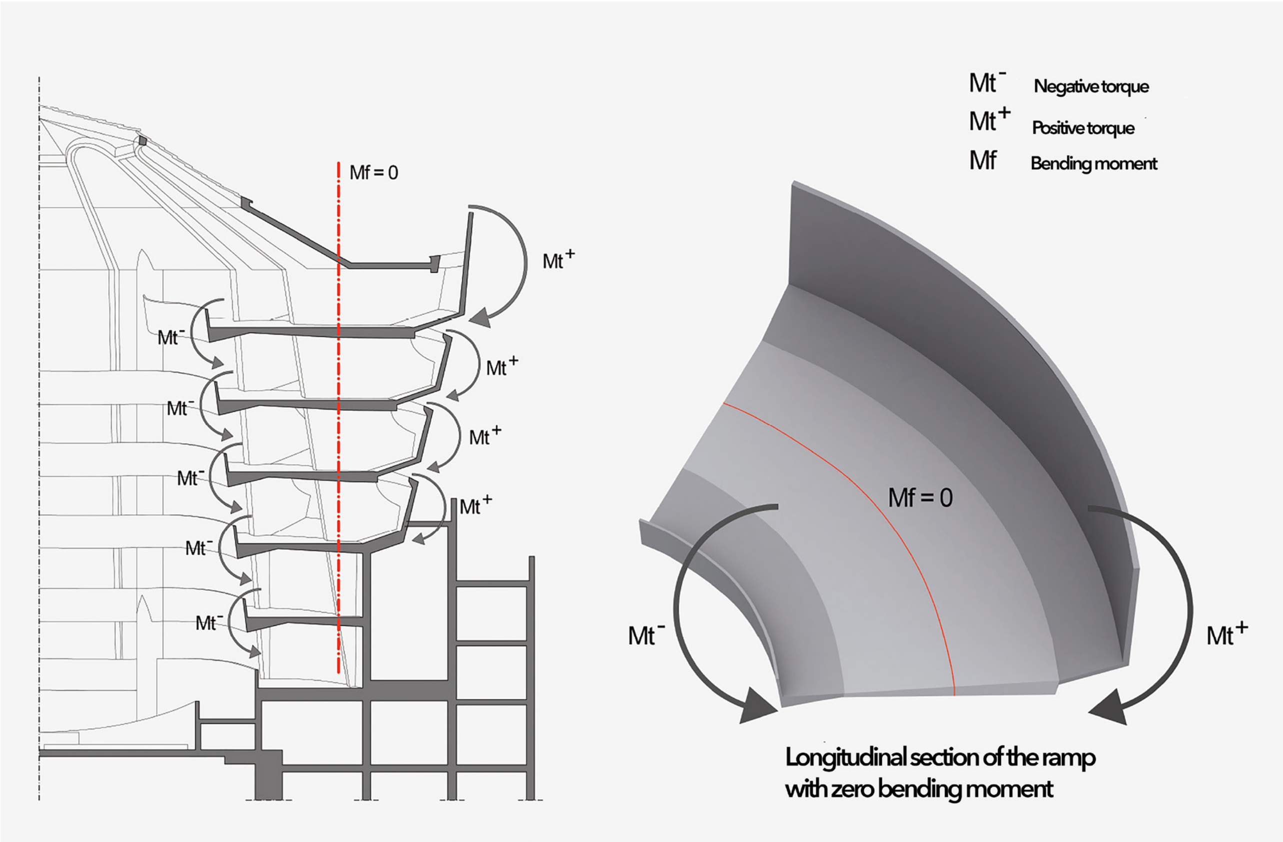
But if on the one hand the inward cantilever produces a negative rotational force at the longitudinal section of the ramp, on the other it is still an overhang, in this case the external masonry, that cancels out the stresses in the same section confirming the synergistic behavior of the entire structure (fig. 9). The collaboration between the analyzed elements must evidently have been very

Fig. 8. Radial walls of the Archeseum: analysis of load-bearing behavior (graphic elaboration by the author).



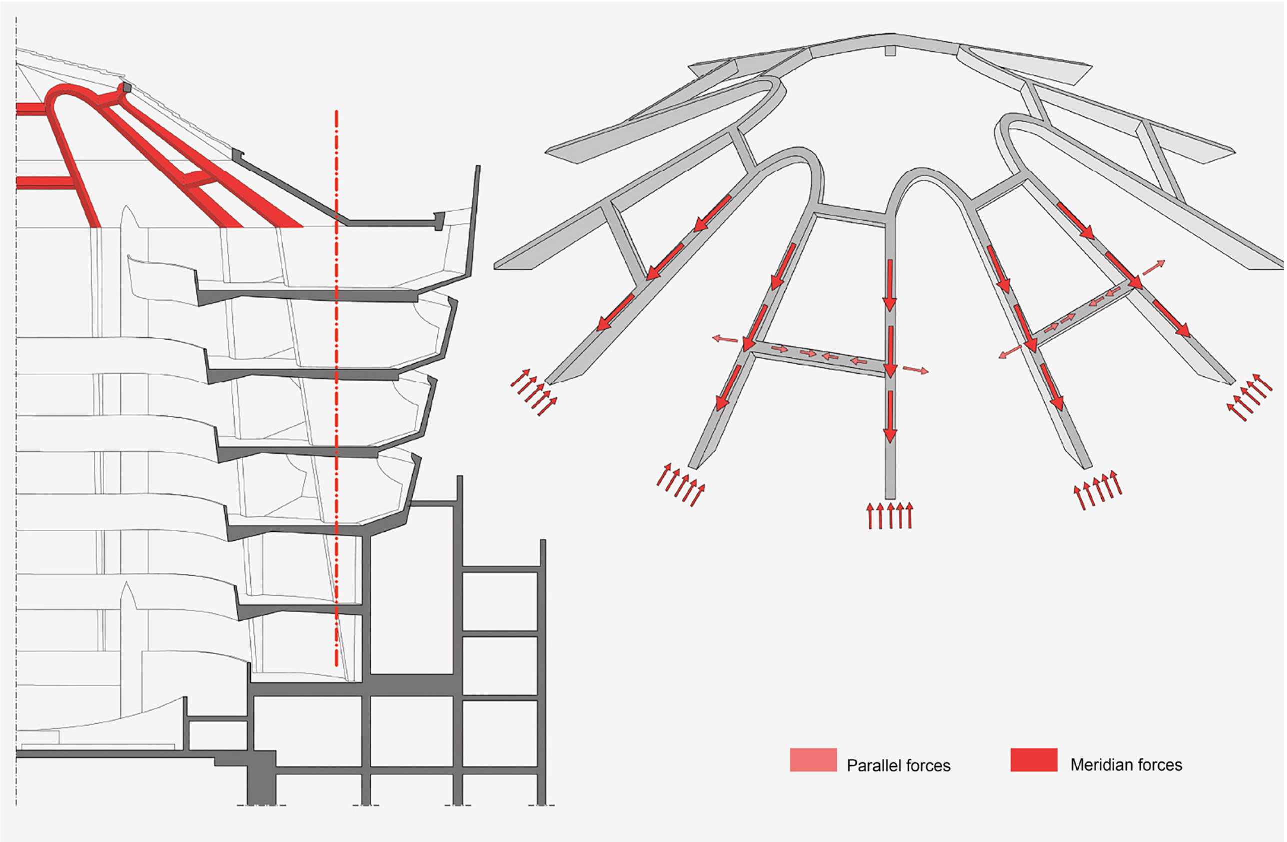
carefully considered by Wright from a static point of view, since the longitudinal section of the helicoid ramp, despite being the geometric location where vertical stresses are most felt, is characterized at every point by a zero bending moment, even though the exhibition path increases its width by ascending, rotating, and translating.
This extraordinary balance was achieved only thanks to the increasing progression of the triangular partitions, which allow for an ever-increasing portion of the ramp to be accommodated while the internal and external overhangs maintain their mutually constant dimensions on each level. This is why, being subjected to the same opposite torsional moments at every point, the helicoid ramp exhibits a bending moment equal to zero along its entire longitudinal section. This requirement for balancing the longitudinal section of the helicoid ramp also explains the formal reason why the triangles, which constitute the twelve radial partitions, have differently inclined sides – specifically, the internal one by 11 degrees and the external one by approximately 22 degrees. According to Trombetti, proof of this assumption could be attributed to the reduced inclination of the last volute of the external

Fig. 9. Radial walls of the Archeseum: analysis of bending moments (graphic elaboration by the author).



wall, compared to that of the lower floors, caused by the changed conditions induced by the increase in the height of the floor, while the size of the corresponding internal overhang remained unchanged [Trombetti 2007, p. 58].
The last element to be analyzed not only in its static behavior but also in its relationship with the other components is what we have called a dome but which, as we have seen, corresponds to a glass pyramid with a dodecagonal base. The term dome is justified by its static functioning; in fact, the main framework of this element is made up of thin U-shaped beams, which extend from the sixth level, projecting from the twelve radial partitions. These beams are responsible, just as happens with the ribs of a hemispherical vault, for transmitting the so-called meridian forces to the underlying structure, while the small horizontal beams that connect them counteract the parallel forces [Trombetti 2007, p. 60]. The roof, thus conceived, minimizes the load that the underlying structure must withstand, because it does not transmit any bending moment, since the insertion of a beam onto the triangular partition occurs in correspondence with the resultant of the vertical loads (fig. 10).

Fig. 10. Ribs of the Archeseum dome: analysis of meridian and parallel forces (graphic elaboration by the author).



Conclusion

Although brief, the structural analysis conducted here on the Archeseum reveals a profound interaction and collaboration between the architectural elements involved; it is almost as if the architect had wanted to adhere to the famous motto of *lieber Meister* Louis Sullivan: "Form follows function" [Twombly 1988, p. 81]. Keeping in mind the organic direction taken by Wright's architecture, entirely permeated by the transcendentalist philosophy of Ralph W. Emerson e Henry D. Thoreau [Brunetti 1980, p. 102], it would be more correct to affirm that the 'soul' of the Guggenheim Museum precedes and holds together integrating them, idea, form and function.

Notes

[1] The name International Style comes from a book by Henry Russell Hitchcock e Philip Johnson, written for the International Exhibition of Modern Architecture. The exhibition, held at the MOMA in New York in 1932, promoted an architectural movement that had become established in the early 20th century. Some of the leading artists of the time, then residing in New York, including Rudolf Bauer and László Moholy-Nagy, supported the criticisms leveled by Frank Lloyd Wright's colleagues regarding the Guggenheim Museum project and attempted to negatively influence the opinion of the curator, Baroness Hilla Rebay, citing the unorthodox nature of the designer's museography choices. In effect, the American architect was accused of wanting to build a monument to himself rather than a museum for the display of Mr. Guggenheim's non-objective paintings.

[2] Wright can be considered one of the pioneers –along with Louis Sullivan– and the greatest exponent of Organic Architecture, which aimed to achieve a balance between the built and natural environments. The precepts of this design approach, which some scholars have contrasted with Rationalism, were fully expressed in the lectures the American architect gave in London in 1939 [Wright 1939].

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Revealing the Structures and Forms of Propaganda. Patterns and Symbols in the Colonial Architectures of the Mostra d’Oltremare

Giuseppe Antuono

Abstract

In architecture, the relationship between form and structure often constitutes a central interpretative node for understanding the meaning of a work. In particular, in Italian Rationalist architecture produced between the two World Wars, this relationship assumes an ideological value of complementarity: form becomes a symbolic expression of power and tradition, supported by a structure –sometimes displayed, sometimes hidden– that acts as a cultural medium in shaping the spaces of propaganda. This interdependent relationship is evident in the narrative-ideological trajectories of exhibition complexes.
A prominent example is the Mostra d’Oltremare complex in Naples, with particular attention to the pavilions of the Geographic Sector –most of which have been lost– where the interaction between structure and form creates a rhetorical device aimed at sustaining an image of order and power. This image refers to the rich repertoire of overseas imitation models and classical references, often not immediately recognizable and interpretable only through a careful reading of the underlying formal codes.
From this perspective, design assumes a hermeneutic function, aimed at rendering intelligible the original configurative matrices. These are reconstructed through a process of surveying and analyzing historiographical sources and translated into a digital model capable of revealing and reflecting on the relationship between form, constructive logic, spatial organization, and symbolic-functional matrices.

Keywords: Cultural Heritage, integrated survey, digital model, formal re-interpretation, geometric-spatial matrices.

Introduction

In architecture, the relationship between structure and form is a fundamental principle, in which constructive reasoning and formal expression contribute to the definition of space and its symbolic value. This relationship takes on particular significance in Italian architecture during the twenty years of Fascism, where the coexistence of classicist and rationalist demands links formal configuration to the supporting structure through geometric rules that orient the design towards an image in continuity with the tradition and rhetoric of the regime.
A privileged area of experimentation was exhibition buildings, conceived as rhetorical devices in which the structure was configured as an organizing framework capable of modulating spaces and forms according to the political ideology of the time.

A significant example is the complex of the Mostra Triennale delle Terre Italiane d’Oltremare in Naples [Aveta et al. 2021] (fig. 1), inaugurated on May 9, 1940 [AA.VV. 1940b], as a *Universal Thematic Exhibition* [AA.VV. 1940a, p. 9] and organized “like city districts” [Biancale 1940, p. 55]. The exhibition area was in fact divided into four sectors (Geographic, Production, Historical, and Various Exhibitions, Theatre, and Attractions) and described by “ideological axes” that constituted the framework of the “green park” [Siola 1990, p. 2], within which a ‘measured’ design of the pavilions was promoted, consistent with nationalist objectives [Antuono, Elefante 2024, p. 722].
The Geographic Sector is a particularly significant exhibition space, in which the architectural form and

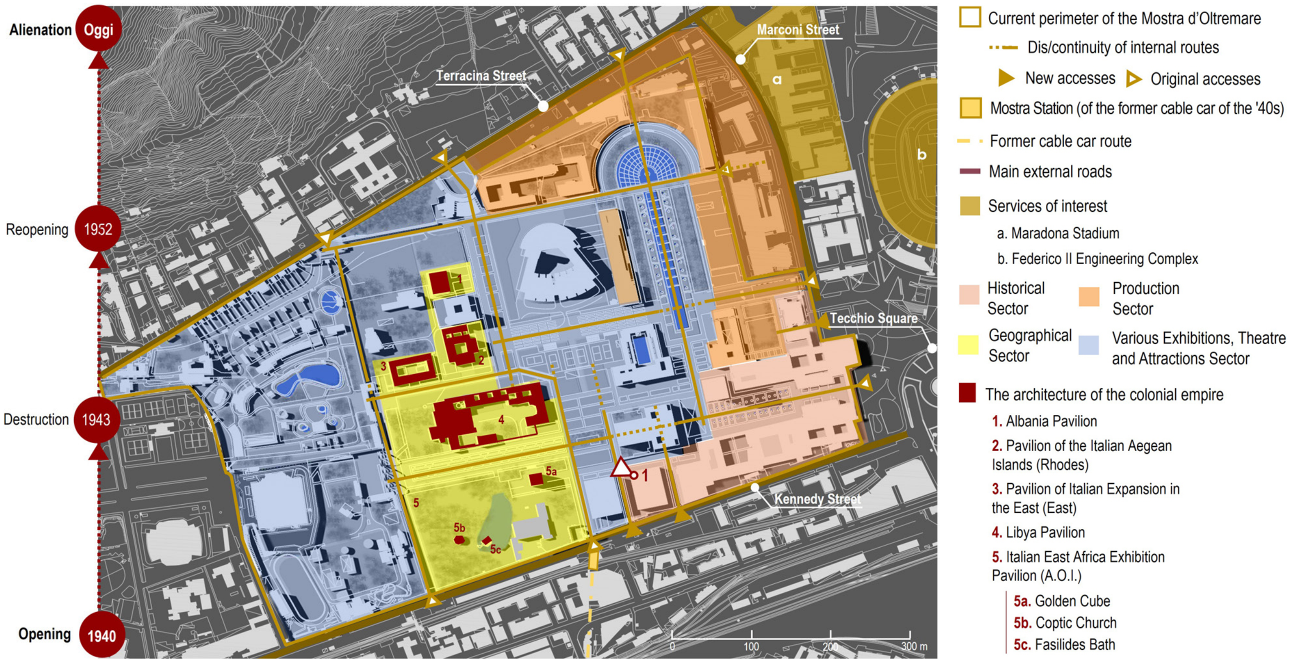

Fig. 1. Overview of the Mostra d'Oltremare Complex, highlighting the original Sectors and the architectures that comprised the Geographic Sector (graphic elaboration by the author).

structure reflect a language steeped in symbolic references, expressing the propaganda imagery of the era and the narrative of identity and celebration of Italianness [Dore 1992, p. 50], aimed at representing the Italian colonial empire.
Today, only a few of the original structures of the Sectors –designed as part of a unified artistic approach by some of the leading figures of Italian architectural culture of the period [Arena 2012, pp. 13, 14]– remain recognizable (fig. 2), albeit in compromised condition. Among these are the Pavilion of the Italian Islands of the Aegean (commonly known as the Rhodes Pavilion) by Giovanni Battista Ceas [AA.VV. 1939a; AA.VV. 1941, pp. 49, 50] and the Pavilion dedicated to Albania, designed by Gherardo Bosio and Pier Niccolò Berardi [AA.VV. 1939b; AA.VV. 1941, p. 54; Penta 1940, pp. 18-24].
Other buildings, however, have been altered by subsequent interventions that have compromised their original layout and meaning, such as the Pavilion of Italian Expansion in the East (commonly the Oriente Pavilion) by Giorgio Calza Bini [AA.VV. 1941, pp. 55-57] and the Libya Pavilion by Florestano Di Fausto [AA.VV. 1941, p. 46]. Very little remains of the original installations in the vast southern area once occupied by the Pavilion of Exhibitions of Italian East Africa (A.O.I., Africa Orientale Italiana) by Mario Zanetti, Luigi Racheli and Paolo Zella Millillo [AA.VV. 1940b, pp. 65, 66]: only the sculptural architecture of the Golden Cube and a few ruins in the adjacent Indigenous Villages Park, which no longer convey the formal and symbolic expressiveness of the original design.
In this context, understanding the residual structures requires a multi-level methodological approach (fig. 3), in which historiographical sources, compared with digital survey data, provide essential metadata for interpreting the metric-formal composition of the artifacts –based on the "ordering" and "sequentiality" of elements [Moretti 1957, pp. 21-30]– and for carrying out a reliable digital philological reconstruction of their original appearance [Trizio et al. 2021].

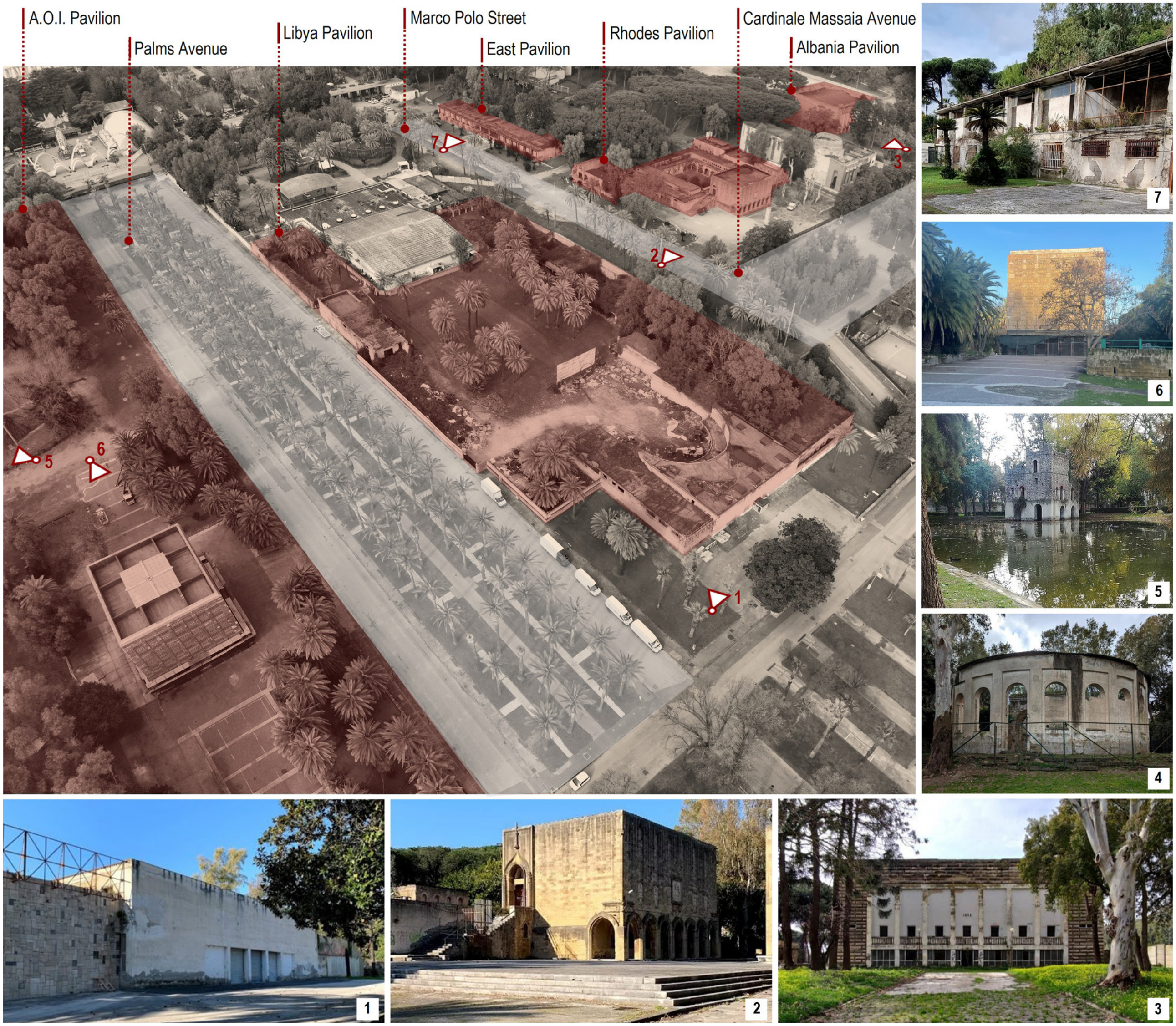

Fig. 2. Aerial view of the Geographic Sector, highlighting the residual configurations of the original pavilions arranged according to the grid of internal pathways of the Mostra d'Oltremare complex (graphic elaboration by the author).

In this regard, representational tools make it possible to retrace the "forms of spatial and design thinking" [Ugo 1994, p. 78] of the pavilions, starting from the analysis of design drawings and the reverse-perspective reconstruction of historical photographic documentation [Agnello 2023], allowing the virtual recreation of volumetric configurations and interior spaces that are poorly documented [Poulopoulos, Wallace 2022].
This process of retro-design [Verdiani 2017] finds in parametric-informative modeling a critical tool useful for validating the coherence between the collected evidence and reconstructive hypotheses [Pietroni, Ferdani 2021], restoring conceptual depth to the original architectural choices, and revealing the hidden order that structures the visible within the dialectic between formal, structural, and ideological dimensions.

The Geographic Sector. From survey to digital reconstruction through historical sources

While largely maintaining its original urban layout, the Geographic Sector has today lost the celebratory aura characteristic of its 1940s configuration, marked by pavilions conceived as an evocative representation of the "synthetic panorama of our modern imperial possessions" [AA.VV. 1941, p. 4] and accessible via four main pathways, defined by rich vegetation serving as a unifying *leitmotif* of the exhibition route [Piccinato 1977] (fig. 2).
In this context, the analysis of the Sector required an integrated approach, combining digital survey data of the residual configurations with information drawn from historiographic documentation, thus building a solid information base [Di Luggo, Campi 2021, p. 252] to understand the rationale behind the current forms and the original compositional and formal choices, as well as to grasp the symbolic and ideological motivations that guided the design of the architectures under study.
In particular, each transformation leaves signs of discontinuity, evidence of more or less consistent restoration or adaptation to new uses, which can be detected from the early stages of reality-based inspection and measurement (fig. 4), conducted using integrated range and image-based digital surveying techniques [Hassan, Fritsch 2019; Barba et al. 2020]. Specifically, aerial photogrammetry (using a *Mavic 3 Enterprise RTK* drone to document elevations and roofs) was complemented by laser scanning acquisition (using the *BLK360* for interior spaces and the *Faro Focus S350* for exterior spaces and pathways), allowing a comprehensive documentation of the Sector's plan-volumetric organization and the residual traces of the structures. Setting aside the well-established procedural aspects of data acquisition and processing, the collected multi-sensor data-integrated into a georeferenced and structured dataset-enabled an initial comparison with the available graphic and documentary sources, supporting the interpretation of the recorded evidence and the reassessment of the transformations affecting each structure, up to the evaluation of configurations that are now lost.
The most significant evidence consists of the design drawings for the exhibition area preserved in the Luigi Piccinato Archive [1], together with descriptions and drawings published in magazines of the time or preserved in the Mostra d'Oltremare Archive [2].
This is complemented by the rich iconographic heritage of the Federico Patellani Archive [Capano 2014; Belli 2016], as well as by materials disseminated through the extensive editorial production promoted between 1938 and 1941, and the numerous cinematic recordings of newsreels [*Giornale Luce* 1940; *La Settimana INCOM* 1952]; together forming an essential documentary corpus for the figurative reconstruction of the original layouts.
True testimonies of history and stories, these documentary sources –through comparative reading and in relation to survey data– have allowed for the interpretation of marks and discontinuities left by transformations, such as wall openings later closed, misalignments between building blocks, and the juxtaposition of different construction technologies, as well as clarifying some aesthetic, functional, and structural aspects of the structures in their original configurations, including volume organization, elevation composition, circulation connections, and spatial relationships among the various building units. A process of interpretation, also supported by the identification of geometric codes underlying the composition of residual parts, enabled the reconstruction of planimetric and altimetric layouts and the rigorous geometric-compositional framework at the base of the pavilions' design; a project showing clear references to overseas colonies architectural models and local construction traditions, reinterpreted in a classicist key to support the regime's rhetoric.
This first re-compositional investigation allowed the structuring of a federated parametric-informative model of the study area, based on a topographic coordination model linked to the architectural models of the individual struc-

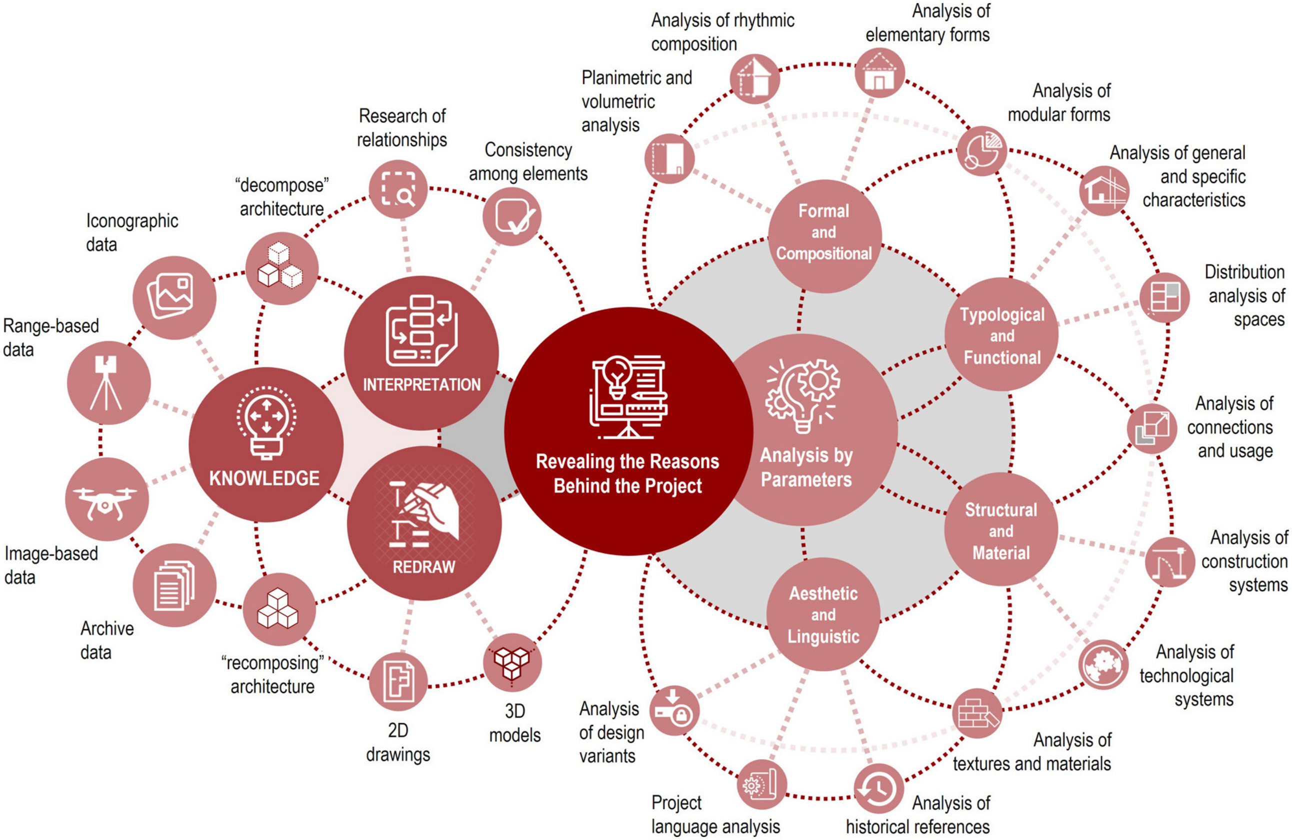

Fig. 3. Methodological framework for understanding and interpreting the visible, reconstructing the graphic model of transformations, and revealing the original layouts, choices, and configurative logics (graphic elaboration by the author).

tures, organized in an aggregative framework that facilitates their reading within the spatial context of reference.
Furthermore, to each architectural model describing the current state of the site, the available graphic and design documentation was associated, allowing the reconstruction of the pavilions' original spatial configuration through digital elements enriched with informative parameters describing technological and material characteristics derived from archival documents. A model that, also integrating the iconographic component –through an interoperable digital workflow of reverse-perspective reconstruction between parametric platforms– provides a coherent, multi-layered system of knowledge, combining documented data, drawings, and digital surveys, useful both for the comprehensive interpretation of the original design dimension [Russo, Guidi 2011] and for the critical verification of preliminary hypotheses regarding the original configuration of individual structures [D'Agostino et al. 2023]. In this way, digital modeling was tasked with reconstructing the evolution of lost architectural and figurative elements in phases, integrating historiographic, graphic, and iconographic components, thus preserving an intangible legacy of the regime's ideological forms and providing a comprehensive understanding of the founding principles of the project.

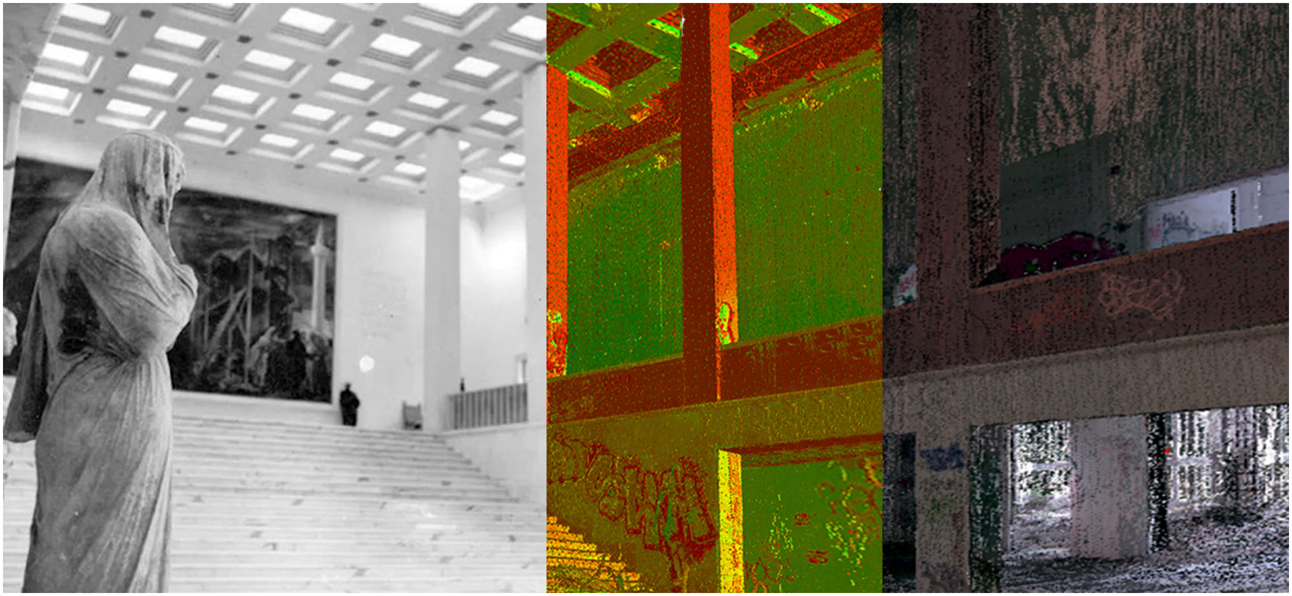

Fig. 4. Interior view of the Libya Pavilion, created as an integrated composition of historical sources [Dillon, 1940, p. 6] and range-based data, to compare current conditions with the original design intentions (graphic elaboration by the author).

Meta-design interpretation of the documentary heritage

The correlation of the acquired sources has made it possible to structure a digital, multiscale, and multidimensional system for the integrated management of the acquired spatial and thematic information, aimed at analyzing the original configurations reinterpreted in the subsequent layout adaptations of the Sector, defined only after the Italian occupation of Albania in 1939 [Belli et al. 2017].
Comparative analysis of historical cartographic documents, conducted through polynomial adaptation, allowed the reconstruction of the temporal invariants of the building complex and the plan-architectural layout of the Sector, organized along two main north-south axes: the first, Cardinale Massaia Avenue, connected the northern access system of the production sector [Antuono et al. 2024] to the Albania and Rhodes Pavilions, passing by the eastern entrance of the Libya Pavilion and continuing toward the A.O.I. Pavilion; the second (today A. Usodimare street), from the entrance to the Various Exhibitions, Theatre and Attractions Sector, ran alongside the Oriente Pavilion and the western entrance of the Libya Pavilion, reaching the A.O.I. Pavilion. The Sector was also served by two east-west axes crossing the Libya Pavilion: the first to the north, Marco Polo street, which provided access to the Oriente and Rhodes Pavilions, and the second, Palms Avenue, which led to the A.O.I. Pavilion, located along the southern boundary of the exhibition complex at the elevated route of the Posillipo Alto-Mostra cable car (fig. 1).
The multi-temporal analysis of the area made it possible to understand the connectivity and accessibility systems and to investigate the original morpho-typological characteristics of the structures that made up the exhibition project.
The pavilions played a central role in the imperial narrative, guiding visitors through "multiple and sudden space-time shifts" [Mangone 2014, p. 210], as evidenced today by the Rhodes and Albania Pavilions, which, despite war damage, retain substantial integrity thanks to

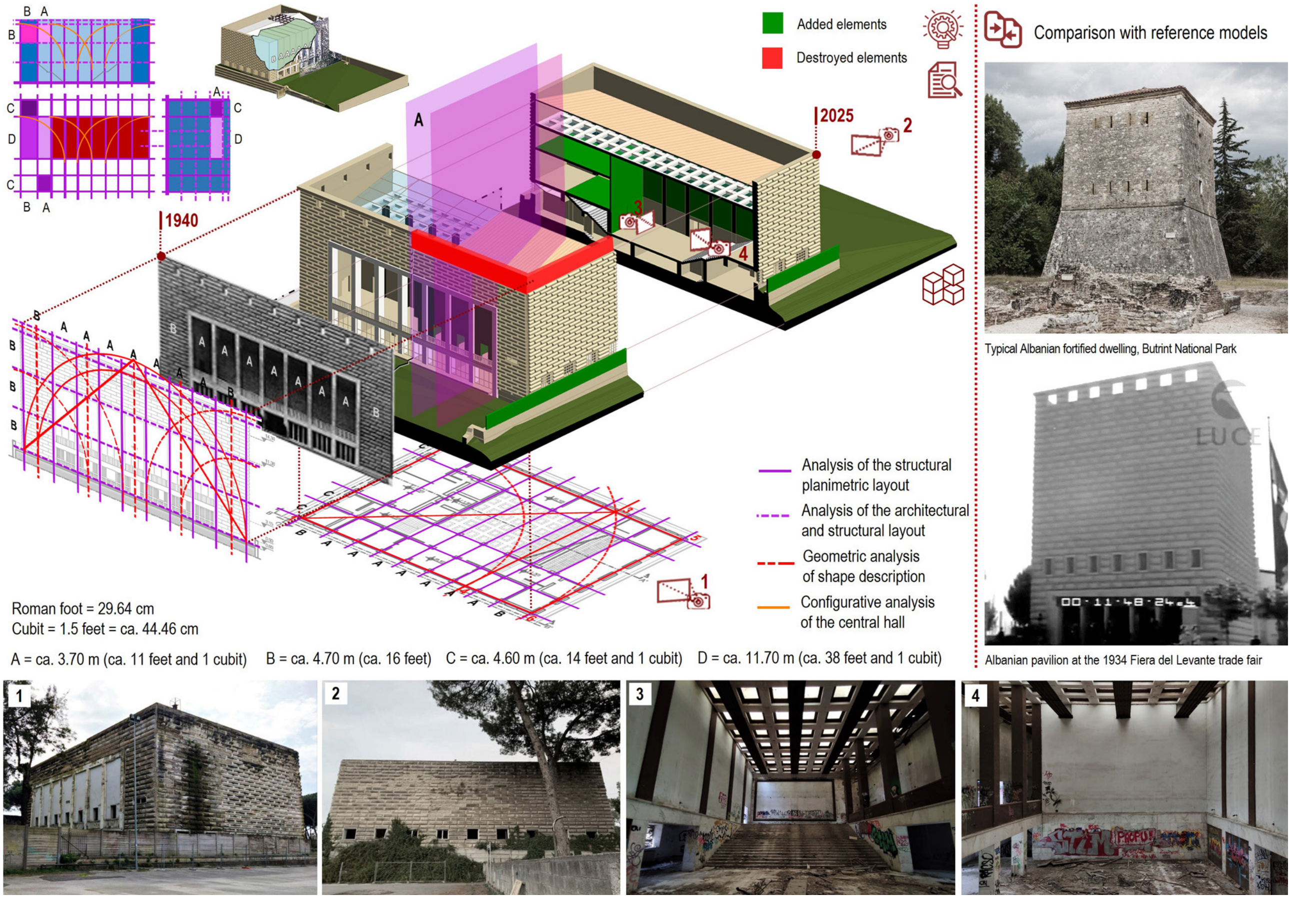

Fig. 5. Digital reconstruction and geometric–proportional analysis of the Albanian Pavilion, carried out through the integration into the model of archival documents - including the orthorectified perspective view of the main façade [AA.VV. 1941, p. 54] - which guided the modular design of the building. On the right: the project reference models; at the bottom: selected images of the current conditions (graphic elaboration by the author).

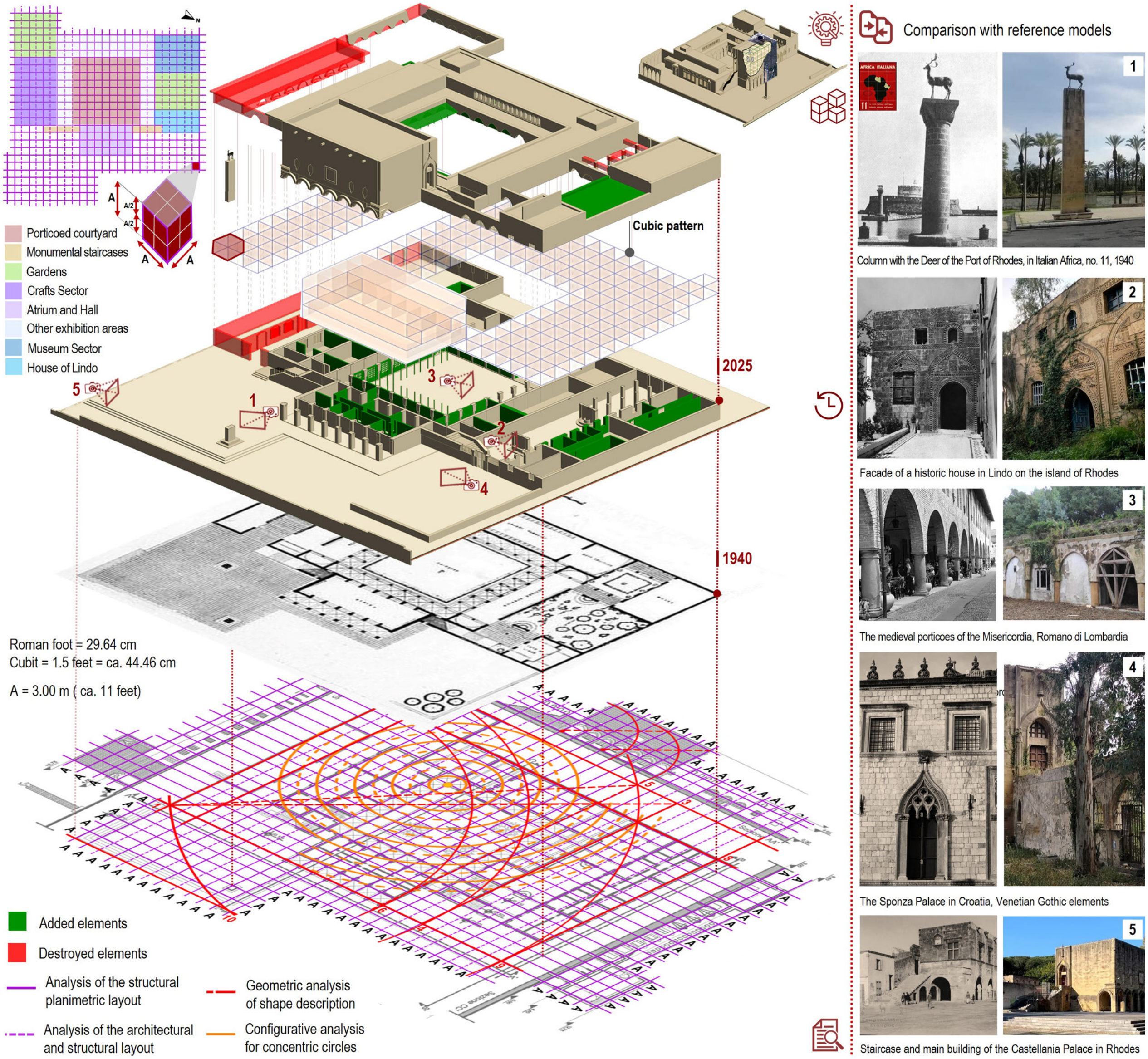

Fig. 6. Digital reconstruction of the Rhodes Pavilion, based on the integration of historical graphic documentation (such as the ground floor plan of the complex, in AA.VV. 1941, p. 50) and the plan-volumetric analysis of the building. On the right, the project reference models, compared with some images of the interior and exterior spaces (graphic elaboration by the author).

coherent restorations carried out during the reopening of the exhibition complex in 1952 as the *Exhibition of Italian Work in the World* [Fiore 1952; AA.VV. 1952].
The discretization of the available metric and documentary information allowed for the analysis of current layouts, the interpretation of the geometric-proportional criteria adopted, and the detection of the units of measurement and modules underlying the composition, typical of the classicist repertoire [Fasolo 1960], facilitating the recognition of design choices and the role of the architectures as models of imitation.
Project drawings alone proved sufficient to reconstruct the formal values of the Rhodes and Albania Pavilions, whose external configurations remain largely original, albeit in a state of neglect and with interior spaces redefined by subsequent interventions, thus providing an essential reference for analyzing their spatial articulation and symbolic content.
In particular, for the Albania Pavilion (fig. 5), decommissioned and in recent years housing the Institute for Economic Development (ISVE), internal modifications have also affected the original monumental external image. The main façade, marked by projecting pillars placed at regular intervals, was originally characterized by a large loggia, now filled in, surmounted by small windows that defined the crowning band of the façade.
The rhythmic dimension of the elements refers to the Roman unit of measurement (feet and its subdivisions). In particular, from the façade, it can be observed, for example, that the interval A between the pillars corresponds to approx. 3.70 m, that is, about 11 Roman feet and one cubit.
The building still retains its classical-inspired rusticated cladding, which, recalling the Albanian fortress-houses Kulla [Mangone 2014, p. 214], describes a compact volume with references also to other Italian exhibition experiences [Pagano 1990, p. 134].
Elevated on a high podium, the building has a rectangular layout determined by a rigorous diagonal ratio [Serlio 1584], which proportionally also governs the plan-altimetric organization of the central hall. This double-height space was originally covered by a ceiling featuring 180 Murano glass coffers and included a pair of staircases leading to the first-floor balconies, on whose walls were placed the paintings Albania Romana by Primo Conti and Albania Fascista by Gianni Vagnetti [L'Abbate, Moscardin 2017]. However, the subsequent redefinition of the building's functions required the necessary rearticulation of the interior spaces to create new rooms, including a conference hall on the southern side –which involved infilling one of the two staircases– and the creation of several rooms on the eastern front, obtained by infilling the external loggia; these modifications altered the monumental-exhibition layout, which today is further compromised by structural degradation.
Similarly, despite the neglect and expropriations it suffered at the end of the last century, the Rodi Pavilion (fig. 6) largely retains its original masonry structure, with clear references to regional architecture, except for the section once used for local crafts.
In this case as well, the articulation of the volumes follows a clear geometric (a segment) or metric (a measure) dimension [Gros 1997] of classical inspiration. In particular, the different units composing the building are framed within a geometric grid with a spacing of approx. 3.00 m (about 11 Roman feet), which also governs the elevation of the façades and the height of the interior spaces, today partially reduced. Furthermore, the different sectors of the pavilion are organized according to a planimetric layout governed by diagonal relationships, which determine the composition of the porticoed façades facing the external square. Unfortunately, the subsequent closure of numerous pointed-arch openings compromised the original permeability between the exterior and the internal porticoed courtyard, located between the original Craftsmanship Sector and the northern core, comprising the Museum and the Casa di Lindo inspired by the typical houses of the coastal villages of Rhodes; a courtyard that forms the true heart of the exhibition route, organized according to a concentric pattern that defines the rhythmic spacing of the columns and, at the same time, dictates the dimensions of the main surrounding exhibition rooms.
The architectural language of the pavilion is distinguished by its square, compact surfaces, which recall the historic Rhodes hotels and accentuate the volume of the main body facing the external square. It is divided into two levels and has two symmetrical external staircases –modeled on the Palazzo della Castellania in Rhodes– which, on the first floor, lead to the Hall of Honor, characterized by a rectangular layout and decorated with a fresco attributed to B. Assenza [AA.VV. 1940b]. In the outdoor square, a slender pillar topped with a sculpture of a deer, reminiscent of the statues on the piers of Rhodes, served as a visual reference to overseas models, establishing a

Fig. 7. Geometric and functional analysis of the Libya Pavilion, based on the survey of the current state of the site compared with the historical project plan (published in AA.VV. 1941, p. 46) and period views (photographs by Federico Patellani, June 1940, Museum of Contemporary Photography, Federico Patellani collection, PR. 324/FT. 7) (graphic elaboration by the author).

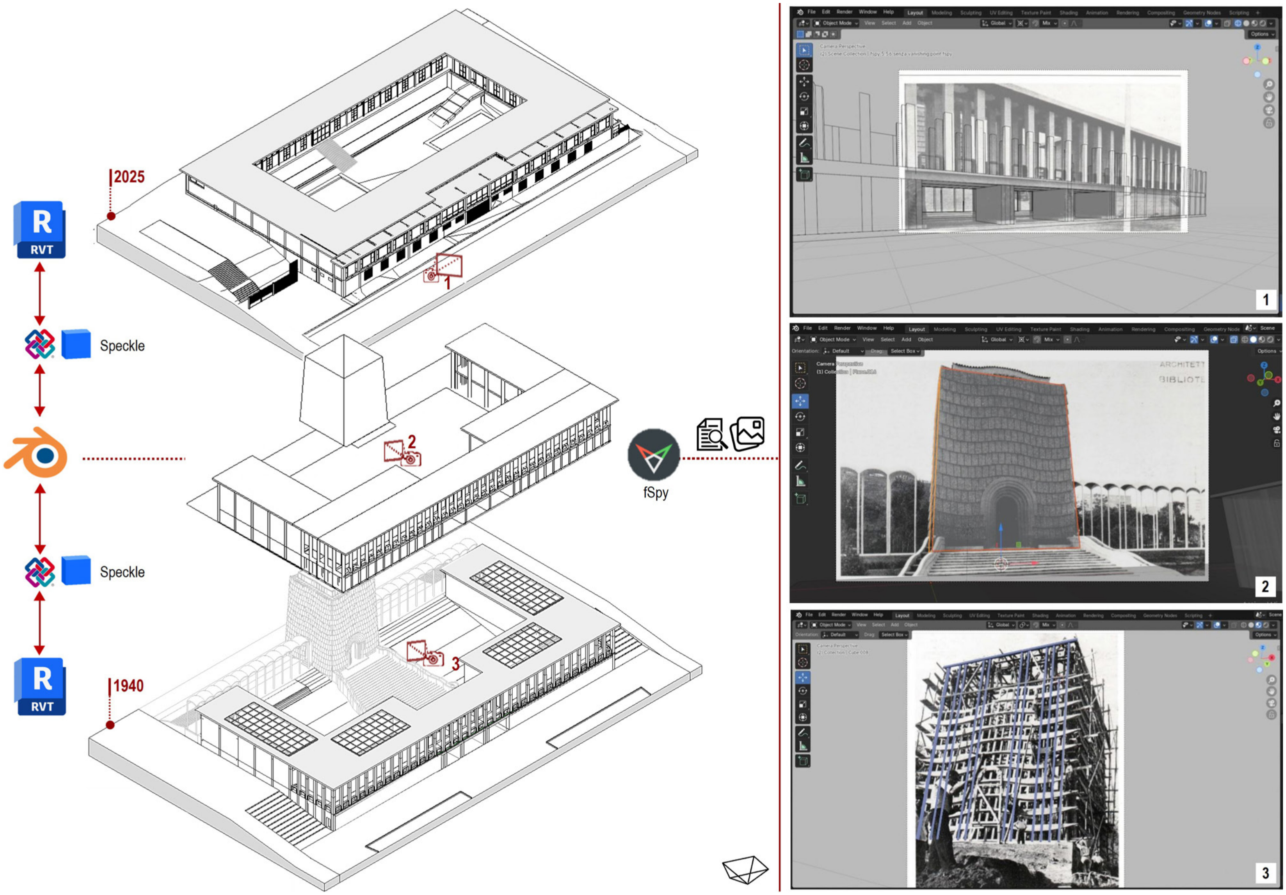

Fig. 8. Operational workflow for the object-oriented reconstruction of the original configurative elements of the Oriente Pavilion, through inverse perspective reconstruction from historical photographs (graphic elaboration by the author).

symbolic link with the nearby Libyan Pavilion (fig. 7). Despite the 1952 renovations, the most representative symbolic structures of the Libya Pavilion were irretrievably lost, further erased by the construction –in the 1960s– of the Centro Bowling Oltremare, built on the most significant area of the complex.
Today, it is no longer easy to perceive the monumentality that characterized the pavilion at the time of its construction, articulated around a large green space and distinguished by symbolic elements such as the white mosque with minaret, the marabout, and the artisan workshops [Amore, Aveta 2021], all of which are now completely lost. However, from the analysis of the drawings and aerial photogrammetric surveys, it is possible to reconstruct the regulating layouts of the pavilion, defined by a rhythm expressed through a module *A* (approx. 10 Roman feet) that dictates the organization of spaces similarly to what is observed in the Rhodes Pavilion.
However, the planimetric and volumetric composition of the pavilion cannot be reconstructed with certainty based solely on the available design drawings, due to the lack of precise altimetric data. This therefore requires an indirect digital reconstruction approach, based on a critical correlation between iconographic sources and residual elements. In this context, historical images represent invaluable sources for restoring the spatial perception and symbolic significance of the lost volumetric arrangements, which would otherwise remain undocumented, provided they can be referenced to a metric system consistent with the digital model representing the current state of the site.

From iconographic data to digital form: images and visions of lost spaces

To support the digital reconstruction of the historical memory of the sites of "the last and perhaps most effective example of the evolution of Italian colonial representations" [McLaren 2011, p. 28], not fully documented by the original project drawings –which, while constituting the main source on the original layout, are sometimes partial or simplified, with omissions of formal and construction details due to adaptation to the chosen scale of restitution– the tools of digital representation offer modeling procedures capable of deriving information on visible architectural forms and details from period

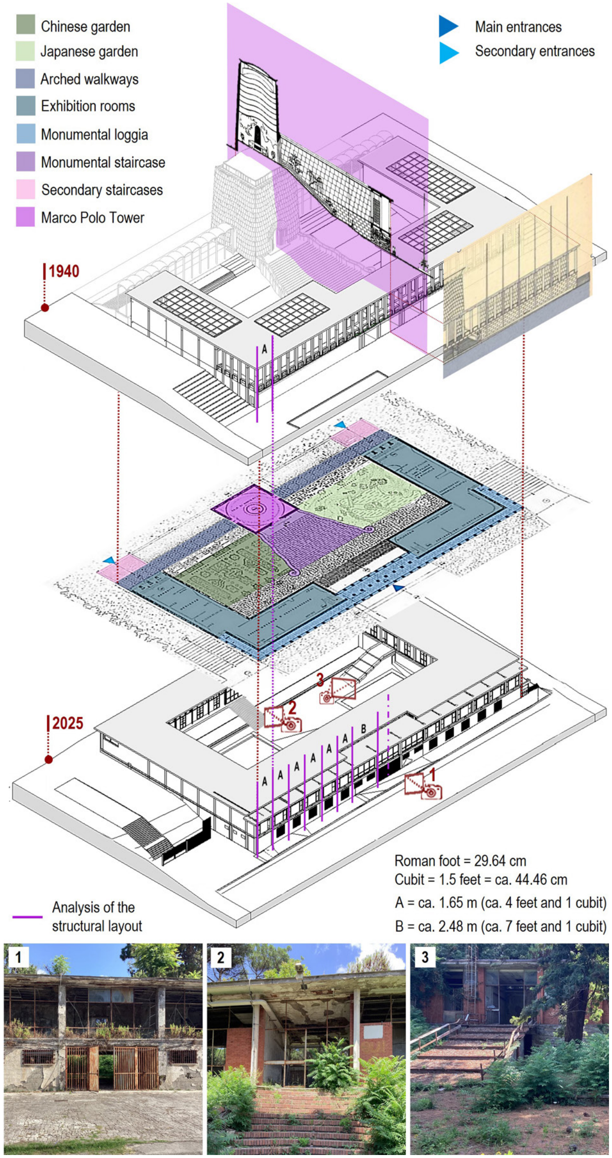

Fig. 9. Digital reconstruction of the Oriente Pavilion, based on the integration of historical documentation [published in AA.VV. 1941, p. 55; Siola 1990, p. 130] and on the spatial and functional analysis of the spaces in their original configuration, compared with the current state of the site (graphic elaboration by the author).

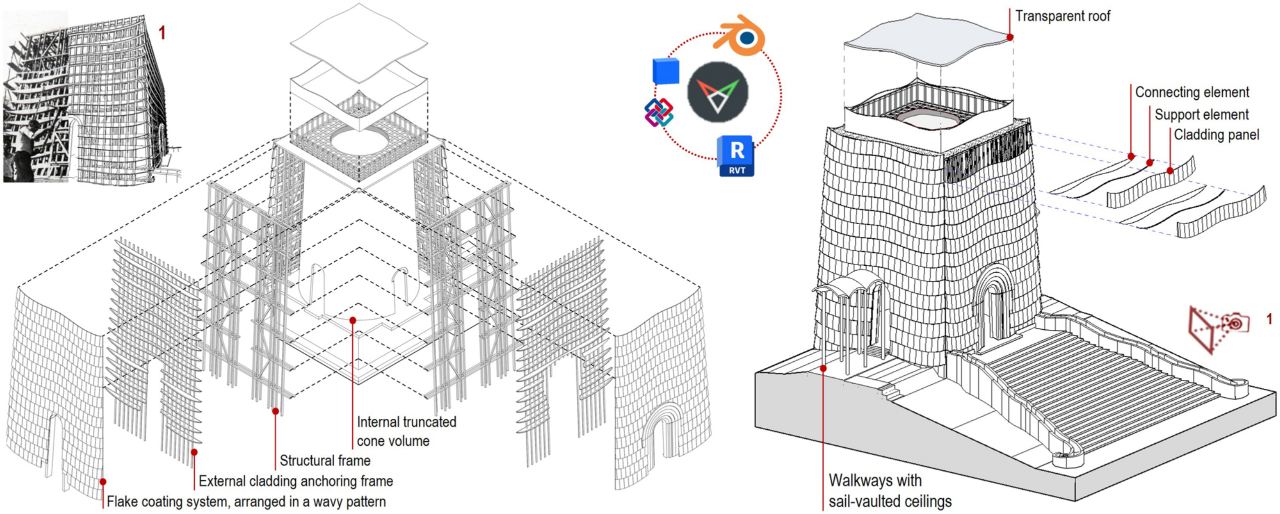

Fig. 10. Exploded digital reconstructions, based on historical images, illustrating the structural and formal components of the Marco Polo Tower (graphic elaboration by the author).

perspective images, depending on the quality of the sources, validating or refusing previous reconstruction hypotheses [Giammusso 2014], and allowing the analysis and reconstruction of the original configurations of those buildings that were deeply transformed and have a limited documentary corpus, such as the Oriente Pavilion and the A.O.I. Pavilion.
In particular, the interoperability between *Blender* and *Revit* (fig. 8), ensured through *Speckle*, allows us to integrate the digital ex ante description of a site not only through conventional graphic-technical documents, but also by exploiting perspectives from period photographs. The latter are analyzed using the freeware tool *fSpy*, which estimates the intrinsic and extrinsic camera parameters, configuring one-, two-, or three-point perspective scenarios, and ensuring accurate geometric alignment between the digital model of the site's current state and historical images. Indeed, for buildings primarily documented through photographic views, often characterized by a lack of information on the internal orientation parameters of the camera, modeling is based on the preliminary analysis of invariant elements, and on those architectural elements that retain their original position, orientation, and proportions relative to the evidence observed in *situ*. These elements constitute the supporting structure of the perspective-reconstruction model, allowing the adaptation of drawings to reality, the reconstruction of plan-altimetric relationships and undocumented detail elements, and the provision of a coherent and philologically founded representation of the original configurations.
For the Oriente Pavilion (fig. 9), whose front façade and cross-section do not allow a complete description of the design plan realized in 1940, historical images can be linked to metric tools capable of reconstructing not only the overall form but also the perceptual and compositional qualities, allowing the reconstruction of otherwise undocumented elements. The building, subject to profound transformations –and today closed to the public by an iron fence that also encloses the area of the nearby Rhodes Pavilion– retains only minimally the refined scenography and the suggestion of an oriental microcosm that characterized the original configuration according to a dual stylistic register: severe and solemn on the exterior, delicate and oriental on the interior.
The quadrilateral building retains few traces of its previous structures, including some pillars that formed the main façade on Via Marco Polo, sufficient to restore the rhythmic pattern of the original open loggia on the

second floor, rationally organized according to a module equal to half of the current one *A* of approx. 1.65 m (approx. 4 Roman feet and 1 cubit) and set on a high continuous base interrupted by only three large portals, decorated with bas-reliefs, which constituted the main entrances to the pavilion.
The mapping of markers from aerial and terrestrial views allowed the reconstruction of the elevation rhythm of the façades and the height of the original roof relative to the current state, highlighting the differences introduced with the reorganization of the building as the Pavilion of Credit and Insurance Activities in 1952, and enabled the reconstruction of the articulation of the lost rear building, whose focal point was the Marco Polo Tower.
Built with a wooden frame structure (fig. 10), the Tower was part of a highly axial scenographic layout designed to guide visitors on a perceptual and symbolic journey from the outside to the central courtyard of the pavilion, organized into two gardens –Chinese and Japanese– which served as a place of mediation before ascending the Tower via the wide staircase.
The exhibition path was strongly oriented and emphasized by the monumentality of the staircase, with its flared plan profile and sinuous plastic parapets, accentuating the verticality of a Tower conceived as a compact square-plan volume, clad in overlapping modular panels which, enhanced by the play of light and shadow, evoked materials and ornamental motifs of oriental inspiration, as documented by historical sections and surveys.
The zenithal lighting of the tower accentuated the solemnity of the space, while also conveying a sense of suspension and lightness. From this point, the symbolic path developed in a double circular direction through two slender porticoes on the north side, surmounted by ribbed vaults resting on slender pillars, which led visitors to the side exhibition rooms and the open loggia on the main façade, ensuring continuity between interior and exterior spaces, an expression of the guiding principle of the project, according to which architecture and landscape had to coexist in a single, all-encompassing experience, which can now be perceived once again through the object-oriented model.
The digital model therefore becomes a hermeneutic tool, capable of making intelligible forms and structures charged with propagandistic rhetoric, as evident in the reconstruction of the A.O.I. Pavilion (fig. 11). A "place within a place", documented as the most important

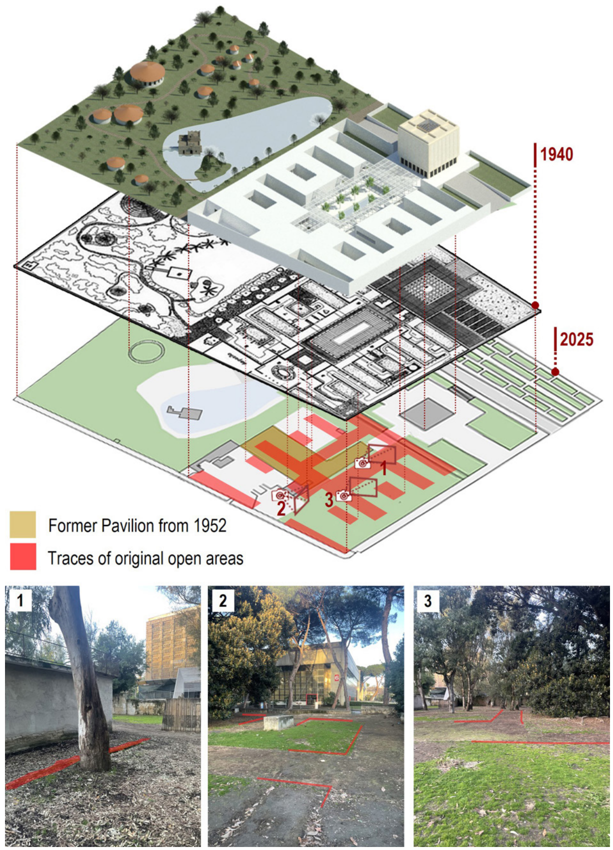

Fig. 11. Digital reconstruction of the A.O.I. Pavilion, based on the original plan [historical documentation published in AA.VV. 1941, p. 41] and on the survey of the evidence still present in situ. Note how the layout of the Pavilion, built in 1952 and organized according to an asymmetrical arrangement with respect to the Golden Cube, adapts to the traces of the original structures of the A.O.I. Pavilion (graphic elaboration by the author).

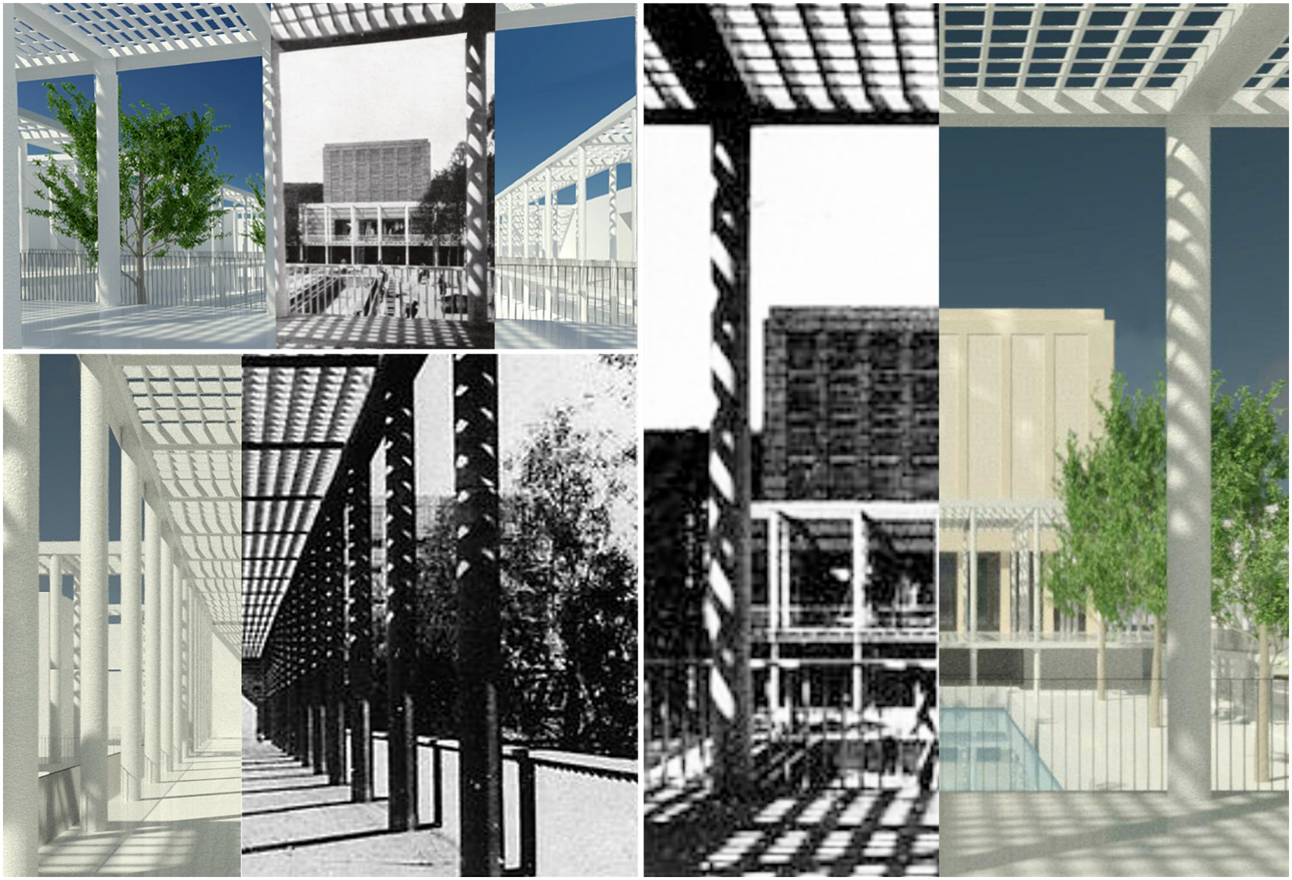

Fig. 12. Views of the evocative pathway along the walkways of the A.O.I. Pavilion, compared with historical views [AA.VV. 1941, p. 42; AA.VV. 1940d] (graphic elaboration by the author).

overseas possession [Pagano 1990, p. 126], built around the Golden Cube that "rose almost mid-air against the background of the Phlegraean hills" [AA.VV. 1940c, p. 54], clad in neo-Egyptian-inspired golden mosaics that evoked the grandeur of great civilizations of the past, ideologically recalling the Roman Empire, which left a significant architectural trace in Africa [Carli 2005]. A series of walkways (fig. 12) extended from the Cube, supported by slender circular pillars and covered by sunshades made of grid panels (fig. 12), leading to the seven pavilions dedicated to the Italian colonies in the Horn of Africa (Eritrea, Somalia, Harar, Hamar, Galla and Sidama, Scioa) [Labanca 2025]. Although these buildings are now completely lost, the surveys (fig. 11) show how the post-war transformation, which led to the construction of the former Italian Labor in Africa Pavilion in 1952, designed by Giulio De Luca [Renzi 2012], was adapted to the original configuration: the layout of the original pavilions is still visible through the arrangement of the greenery, which follows the open areas of the original layout and provides useful elements for the planimetric reconstruction of the buildings. Moreover, the original layout was completed on the western side by the Fasilides Bath, an evocative reproduction of the Ethiopian Castle of Gondar, and a village including a Coptic church, *tucul* [Ascione 2021, p. 154], *hudmò*, and *ghebì* [Palomba 2021, p. 572]. Visitors, traversing these settings, were immersed in shifting atmospheres, now once again perceptible thanks to the digital reconstruction. These models, far from being mere graphic simulations, become interpretative tools for critically reading spatial and compositional relationships, the connections between structure and form, and the constructive and formal principles of the original design, and for supporting future activities in the knowledge, transmission, and valorization of significant segments of modern architectural heritage.

Conclusions and future developments

The figurative program analyzed reveals an architectural invention in which structural dimension and formal expression combine to construct a self-celebratory message which, enriched by exotic suggestions typical of overseas references, conceals the regime's obsession with traditional codes of identity. It is an indirect architectural narrative, now difficult to perceive due to the largely lost configurations, which integrates references to classicism and Roman culture that can only be revealed through a digital reinterpretation of the sites. In this context, the integration of heterogeneous analog-digital data into a relational information model, conceived as an 'open knowledge system', represents an opportunity to reveal the order of meaning of residual spaces and elements and, also through new modes of sharing and AR/VR use, to recount many of the lost or inaccessible architectures of the geographical sector of the Exhibition, while at the same time becoming a tool for enhancing the architectural heritage.

Credits and Acknowledgments

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Notes

[1] The archive, which belongs to the PDTA Department of La Sapienza University in Rome, is available in open access at: https://www.archivioluigipicci nato.it/ (last accessed September 2025).

[2] The Archive preserves a rich and varied collection of graphic and documentary material, which can be consulted thanks to the Framework Agreement between the Department of Civil, Building, and Environmental Engineering of the University of Naples Federico II (scientific directors: Prof. Pierpaolo D'Agostino and Eng. Giuseppe Antuono) and Ente Mostra d'Oltremare S.p.A. (scientific directors: Dr. Remo Minopoli and architect Pio Nicola Perfetto).

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The Palatine Chapel Revealed: Methods and Tools for the Geometric Interpretation of Aachen Cathedral

Martina Attenni, Carlo Bianchini, Marika Griffo

Abstract

This study presents an integrated workflow combining digital surveying and 3D modeling for the geometric analysis of architectural surfaces, with application to the vaulted system of the Palatine Chapel, the Carolingian nucleus of Aachen Cathedral. Since 2022, a collaborative research initiative has conducted an extensive 3D survey of the entire complex. Based on these data, the investigation addressed the morphology of the vaulted structures, focusing on their geometric genesis. The chapel is organized around a central octagon with three levels, surrounded by two ambulatories that mediate the transition to a sixteen-sided perimeter. The lower ambulatory, covered by groin vaults alternating quadrangular and triangular bays, produces a highly permeable space. The upper ambulatory is more articulated, defined by semicircular arches that structure spatial rhythm in plan and elevation, with radial chapels and triangular transitional units. The analysis distinguished the geometric principles of triangular and quadrangular vaults by comparing ideal mathematical models with point cloud data. The proposed workflow proved effective in linking constructive knowledge with morphological analysis, clarifying the relation between design intent and built form. The results provide new evidence on medieval construction processes, reference models, and the technical expertise required to achieve complex vaulted systems.

Keywords: 3D surveying and modeling, Early medieval vaults, Palatine Chapel, Aachen Cathedral, stereotomy

Introduction

Within the broader framework of the *Aachen Cathedral Project* [1], the study focuses on the original Carolingian core of the monument, the Palatine Chapel, in particular on the vaults of the annular ambulatory that surrounds the large central octagon, with the aim of investigating their geometry and constructive logic.

As illustrated by Bruno Schindler [Pieper, Schindler 2017], the chapel presents a vertical articulation in multiple levels for both the external ambulatory belt and the central octagon. To this vertical segmentation is added a horizontal sequence, which, level by level, distinguishes progressively less 'public' areas from the entrance toward spaces reserved for the officiants (fig. 1).

On the ground floor it is possible to identify a radial ambulatory composed of a succession of polygonal rooms, each one story high, likely intended for the faithful, as in a parish church (shown in blue and light blue), contrasted with a triple-height space within the central octagon reserved for the clerics (in green). On the upper floor, given the central void, the layout assigned the sector adjacent to the *Westwerk* to the emperor, while the remainder of the ambulatory likely accommodated members of the court. Opposite the *Westwerk*, on both levels, were the altars (in red), both visible from the imperial throne.

As previously discussed [Bianchini 2024], this spatial configuration of the Palatine Chapel proves highly dissonant

precisely as a result of the opposing tensions between the ambulatories: centripetal on the ground floor, centrifugal on the first floor, seemingly resolved only within the central triple-height void. Alongside other evidence, this sophisticated arrangement suggests that the Palatine Chapel is the product of an extremely clear program in the mind of the designer, who meticulously calibrates the role, form, and function of each architectural component in pursuit of its realization.
The unusual geometry of the complex vaulted systems covering the ambulatories exhibit not only reveals knowledge and skills apparently inconsistent with the conventional know-how of the 8th century but also reinforces the idea that the Palatine Chapel was conceived as a unified project, essentially autographic and rigorously controlled from design to execution. This points to the presence of a single designer endowed with considerable autonomy, currently identified as Odo of Metz.

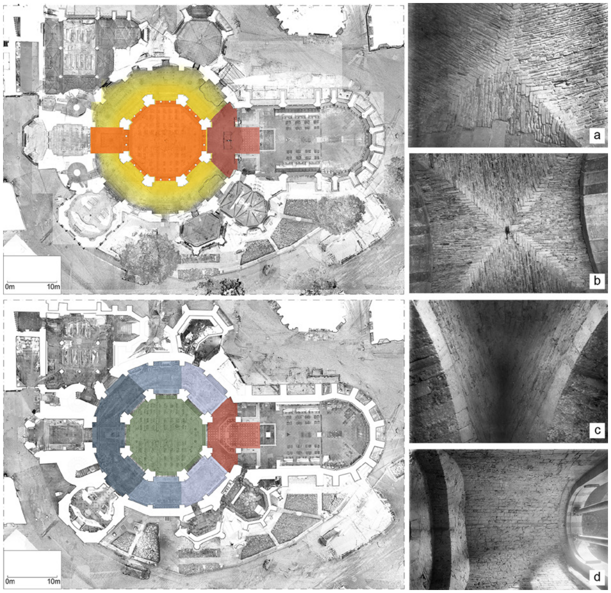


Fig. 1. Spatial organization of the Palatine Chapel according to Bruno Schindler: ground floor for the faithful (blue) and clerics (green); imperial octagonal oratory (orange); first floor for the court (yellow); sanctuaries on both levels (red). Right: vault typologies (© Photo Archive of Aachen Cathedral).

Palatine Chapel

The Palatine Chapel is most eloquent manifestations of Charlemagne's political and religious program, recalling Late Antique and Byzantine models known to the Emperor prior to the construction of the chapel [Ulrike, Beckmann 2012]. It introduces original solutions, particularly in the conception and construction of the vaulted systems, which makes it unique within the architectural panorama of the 8th-9th centuries.
Comparison with coeval monuments confirms this distinctiveness [Pieper, Schindler 2017; Attenni et al. 2023]. For instance, unlike the Basilica of San Vitale in Ravenna where the galleries are recessed and the dome was lightened by the use of fictile tubes, at Aachen the masonry is entirely executed in stone and brick, while the uninterrupted spatial continuity of the ambulatories up to the octagonal core provides the ensemble with a pronounced distributive and visual unity. Other examples of centrally planned architecture, such as the Mausoleum of Santa Costanza in Rome or St. Gereon in Köln, share with the Carolingian Chapel the pursuit of compositional unity, yet they do not exhibit a comparable degree of experimentation in constructive and geometric solutions. In this respect, the Palatine Chapel may be regarded not only as a re-elaboration of existing models but as a moment of advanced geometric and constructive experimentation.
The differentiation between the two levels of the ambulatory renders this experimentation particularly evident. On the ground floor, a system of groin vaults (figs. 1a, 1b), distributed across quadrangular and triangular bays, ensures visual and distributive continuity consistent with the processional function of the space. By contrast, the upper ambulatory displays a more articulated spatial organization: semicircular arches link the inner piers to pilasters set into the outer wall, subdividing the space into clearly defined bays (figs. 1c, 1d). Here, radial chapels provide an alternation between open and more intimate areas, suited to specific liturgical practices, while the triangular transitional sectors act as connective elements between the inclined barrel vaults and the external structural framework.

Research objectives

The survey campaigns conducted from 2022 to 2024 have produced a high-resolution three-dimensional numerical model. Geometric analysis of these data reveals that the

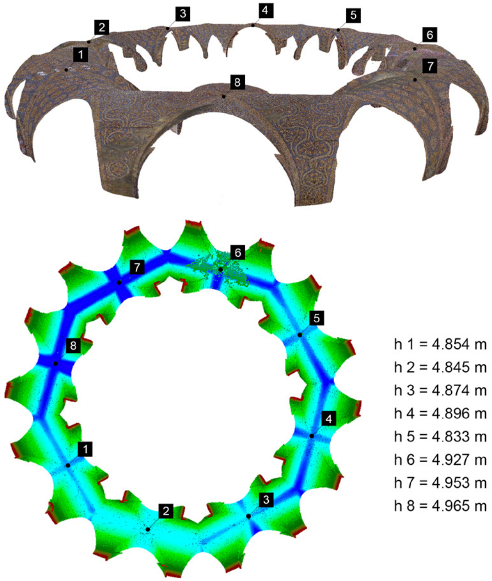


Fig. 2. Top: numerical model of the groin vaults; bottom: elevation map visualization and ridge height analysis of the quadrangular-plan vaults (elaboration by the authors).

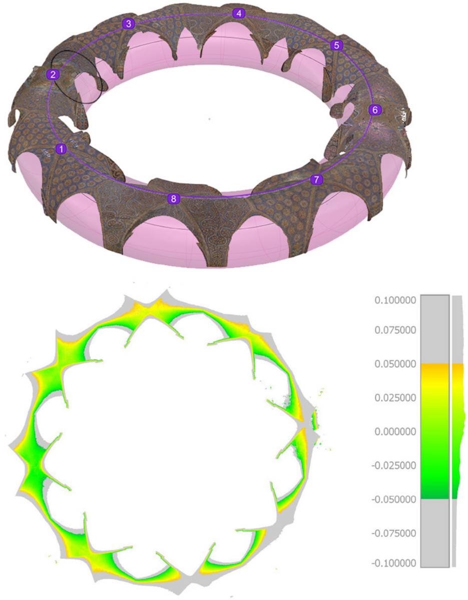


Fig. 3. Top: modeling of the annular vault; bottom: cloud-to-mesh distance within a ± 5 cm range (elaboration by the authors).

various vaulted systems were conceived according to distinct yet coordinated geometric logics, expressing a design articulation that goes beyond mere structural functionality. The research has a twofold objective: on the one hand, to clarify the generative principles of the different types of vaults; on the other, to investigate their meaning within the broader framework of Carolingian architectural culture, assessing whether they stem from conscious knowledge or from pragmatic responses to construction and spatial constraints. The study redefines the role of the Palatine Chapel as a laboratory of geometric experimentation, capable of integrating structural, symbolic, and functional requirements into an innovative architectural language.

Geometric genesis of groin vaults

The lower ambulatory of the Palatine Chapel forms a continuous ring surrounding the central octagon, articulated into quadrangular and triangular bays covered by groin vaults. A first interpretative hypothesis considered these vaults as the outcome of the intersection between an annular vault and radial cylindrical surfaces. To test this hypothesis, the survey data were directly analyzed, visualizing the elevation values of the ridge lines through the elevation map function [2]. The visualization clearly showed that the ridges are not aligned on a single plane nor do they lie on a common circumference, as would be expected from a toroidal construction.
In order to verify the reliability of this observation, the graphical evidence was cross-checked with direct measurements on the point cloud, focusing specifically on the ridge heights of the vault intrados. The recorded elevations range from a minimum of 4.83 m (bay 5) to a maximum of 4.96 m (bay 8), with an overall variation of about 13 cm. For most of the bays (1 to 5 and 6 to 8), deviations remain within a range of ± 2-3 cm, while a sharper discontinuity is observed between bays 5 and

6, which may reflect a differentiated building phase or subsequent structural deformation (fig. 2).
To further verify that the ridges are not actually arranged along a circumference, an ideal torus was generated by translating a circular section –derived as the mean of several circumferences obtained from radial vertical slices of the annular path– along the ring trajectory. The average radius of this circle was 2.32 m, resulting from a range between 2.27 and 2.38 m. The comparison between this theoretical surface and the point cloud, however, revealed significant discrepancies: only a limited portion of the data fell within the ± 5 cm tolerance range (fig. 3). Corroborated by the elevation map analysis, this outcome led to the rejection of the annular generation hypothesis for the groin vaults. Additional confirmation is obtained by interpolating the ridge lines of the groin vaults within a polygon. The resulting figure is an octagon with sides measuring on average 8.85 m, except for a single longer one (8.99 m), corresponding to the octagon that defines the original layout of the Palatine Chapel [Buchkremer 1955].
The investigation was then redirected toward reconstructing the groin vaults as the intersection of cylindrical surfaces. For the quadrangular bays, two cylinders with radii of 2.52 m and 2.32 m were identified, whose intersections define the ridge profiles of the imposts. In the case of triangular bays, a more complex system was required, based on the intersection of three cylinders: two continuing the geometry of the quadrangular bays (with an average radius of 2.33 m) and a third, smaller cylinder (radius 1.99 m), which allowed the triangular bay to be integrated into the overall structural framework. Modeling these surfaces produced ideal reconstructions of both quadrangular and triangular groin vaults, subsequently compared with the point cloud.
The comparison demonstrated a general coherence between the theoretical models and the surveyed geometries, with deviations usually within ± 3 cm. Such values are compatible with medieval construction tolerances and with possible deformations accumulated over centuries [3]. Nevertheless, certain localized areas, especially at the junctions between triangular and quadrangular bays, exhibited greater discrepancies (figs. 4, 5). These may be interpreted as the outcome of executional flexibility, privileging gradual on-site adjustments.

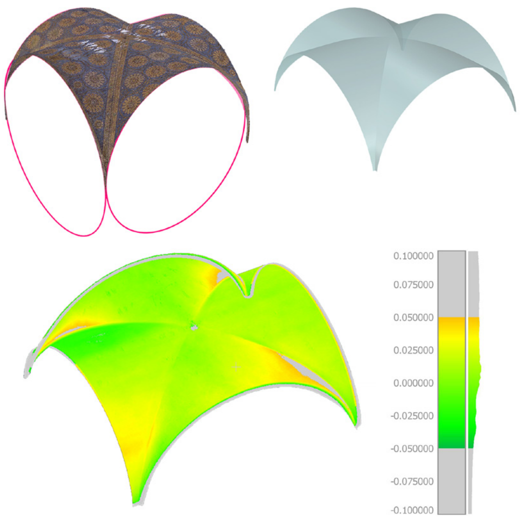


Fig. 4. Top: modeling of the groin vault with quadrangular plan; bottom: cloud-to-mesh distance within a ± 5 cm range (elaboration by the authors).

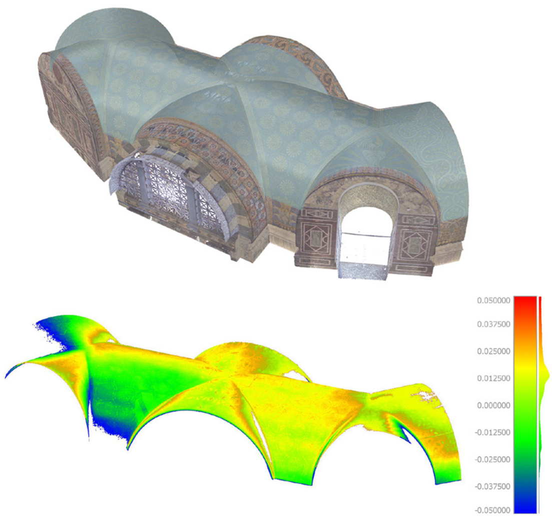


Fig. 5. Top: modeling of the groin vault with quadrangular and triangular plan; bottom: cloud-to-mesh distance within a ± 5 cm range (elaboration by the authors).

From a constructive standpoint, the ground floor groin vaults raise significant questions. The absence of separating arches indicates that the vaulted surfaces were directly sprung from the masonry, likely supported by modular centering elements that could be reused across different bays. The relative homogeneity of the reconstructed cylinder dimensions suggests the use of a limited number of centering models, adapted to the needs of quadrangular or triangular bays.
In terms of generative logic, the groin vaults of the lower ambulatory appear to be based on a rigorous geometric principle –the intersection of cylinders– flexibly adapted to the varying planimetric conditions. This points to a remarkable level of constructional expertise, capable of transforming relatively elementary geometric schemes into an articulated and coherent system that was both structurally stable and spatially effective.
The comparison between ideal models and built reality thus highlights a dual dimension: on the one hand, the design intention of applying a unifying geometric rule based on the groin vault; on the other, the practical necessity of localized adjustments during execution. This dialectic between design and construction provides valuable insight into the organization of the Carolingian building site and the ability of its craftsmen to translate geometric principles into material solutions.

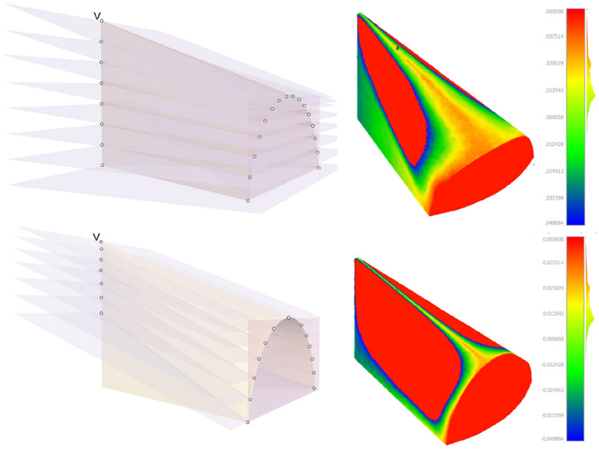


Fig. 6. Top: generic conoidic surface; bottom: conoidic surface with director plane. Right: cloud to mesh distance values in ± 5 cm range (elaboration by the authors).

Geometric genesis of conic vaults

After analyzing the vaulted system of the ground floor, the investigation turned to the conical vaults located in the ambulatory of the first floor [Attenni et al. 2023]. This typology, foreign to the building tradition of the 8th century [Bianchini 2024], immediately proved to be of considerable interest, raising significant questions regarding the level of geometric and technical knowledge attained in that period.
From a compositional perspective, the conical vaults expand towards the vertical outer walls of the chapel, arranged to form a cylinder. As a result, the intersection between the vaulted surface and the cylindrical wall produces a profile described by a skew quartic curve. Beyond the architectural novelty of this solution, such curves are not easily employed to directly describe the geometry of the cone as a ruled surface; for this reason, it was necessary to identify a plane curve to be adopted as the directrix. For this purpose, the curve resulting from the intersection between the vault and a vertical plane passing through the points where the quartic curve meets the springing plane of the vault was chosen. This arc, which closely approximates a circumference, provides an effective representation of the cone's directrix. At the same time, the solution appears consistent with a plausible constructional practice, based on the definition of a semicircular arch with a wooden centering and its subsequent connection to the cylindrical wall.
Although preliminary investigations have already strongly suggested the use of a cone as the geometric matrix underlying the form of the vaults, it was nevertheless deemed necessary to consider two other surface typologies that could be considered equally plausible within the architectural context:

- a conoidal surface with a circular vertical directrix and an oblique director plane parallel to the crown line [4];
- a more general conoidal surface (fig. 6).

The comparison among the three surfaces quickly demonstrated that the conical surface provided the most convincing match with the measured data. Consequently, we proceeded by modeling the vault as a cone, using the two inclined lines at the springing plane as generatrices, taking their intersection point as the

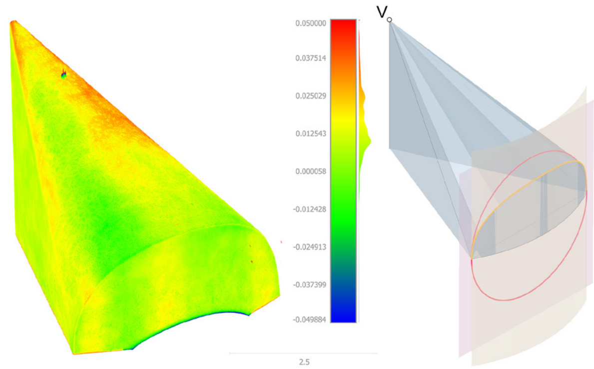


Fig. 7. Left: cloud to mesh distance (± 5 cm) between the point cloud and the cone; right: conic surface intersected by a vertical plane (red) and the cylindrical surface (orange) (elaboration by the authors).

vertex *V*, and adopting the vertical circle previously discussed as the directrix.
We then observed that this conical surface intersected the cylindrical surface representing the outer wall along a quartic curve, which closely approximated the surveyed point cloud.
To further validate the model, the resulting surface was compared with the 3D point cloud using a cloud-to-mesh distance analysis. This comparison revealed a standard deviation of just 1 cm and a maximum deviation of 4 cm at one side of the springing level (fig. 7).
After confirming the strong correspondence between the conical surface and the captured point cloud, we turned to identifying the 'standard' elements of this cone: its axis and its perpendicular base. To construct the axis, we followed a mathematical modelling approach [Salvatore 2012a]. First, we generated a generic sphere with its center at the vertex of the cone. The intersection between this sphere and the conical surface (fig. 8a), together with the intercepted portion of the cone, defined a solid (fig. 8b). The barycenter (*B*) of this solid (fig. 8c), together with the vertex *V*, lies on a straight line representing the internal axis *z* of the cone (fig. 8d). Since the *z* axis is not perpendicular to the circular conic section lying on the vertical plane, the directrix of the cone can be identified as an ellipse. This elliptical curve can be easily constructed by intersecting the cone with a plane perpendicular to the *z* axis. Its geometry is completed by determining the conjugate orthogonal axis (fig. 8e).
To this point, we then reconstructed the circular section of the cone to compare it with the arch used as the conoid's directrix. Indeed, any elliptic quadric cone contains two circular sections. One of these was obtained following the method proposed by Théodore Olivier [Olivier 1852, pp. 199-202], later interpreted through mathematical digital modelling by Marta Salvatore [Salvatore 2012b, pp. 151-154]. The procedure involves constructing a sphere tangent to the sides of the triangle defined by the major axis of the elliptical base and the vertex of the cone. The intersection of this sphere with the cone produces the desired circular section (fig. 8f).
Finally, comparison between this reconstructed circle and the original directrix's curve derived from the point cloud intersection with the vertical plane, revealed a close overlap, differing only by a minor angular rotation.

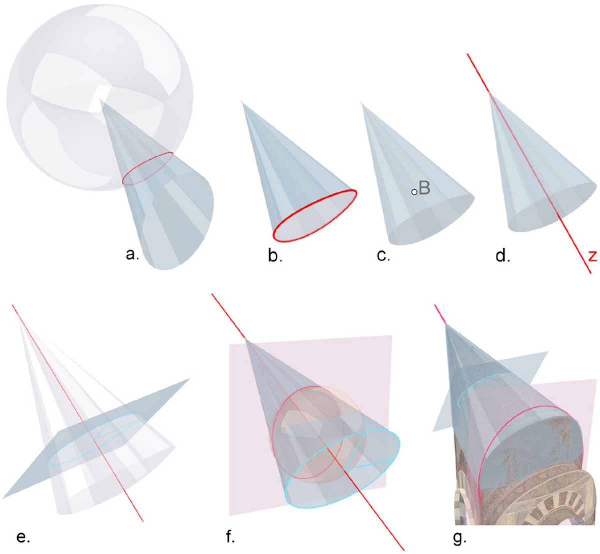
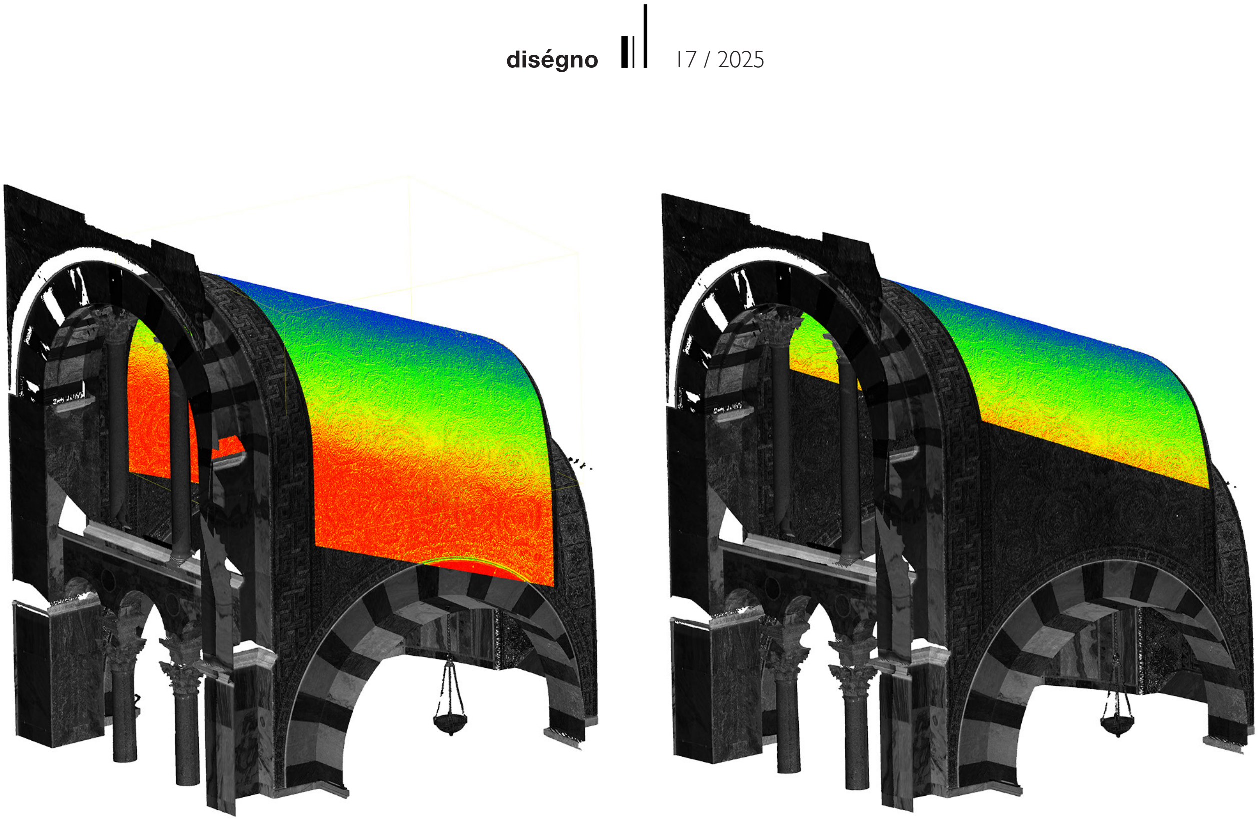


Fig. 8. From a. to d.: construction of the axis of a quadric cone; e.: construction of the ellipse; f.: construction of the two planes that cut the elliptic cone generating circumferences; g.: final reconstruction (elaboration by the authors).



Based on this analysis, we can conclude that the vaults of the Palatine Chapel are indeed conic in shape, and that their on-site construction was plausibly guided by three primary elements: the vertex, the generatrices at the springing plane, and the vertical circular section (fig. 8g).

Geometric genesis of the inclined barrel vaults

The same type of analysis was also carried out on the adjacent inclined barrel vaults, located on the first level of the Palatine Chapel and converging towards the octagonal dome. Although these vaults refer to an architectural and constructional matrix that appears more frequent, the digital reconstruction of this typology has made it possible to highlight peculiar geometric features and to verify the mastery of an architectural practice grounded in a deep knowledge of conic figures and properties.
The first phase of the study focused on identifying the springing plane. To this end, the analysis of the verticality of the points [5] allowed the segmentation of the point cloud of the entire bay, isolating the cylindrical curved surface from the vertical walls (fig. 9).
Then, the construction of the cylinder that best approximated the real surface was initiated, in order to analyze its properties. To understand the type of theoretical surface to interpolate with the point cloud, it was necessary to geometrically examine both the vertical and the transverse sections of the vault. Starting from the identification of the vault crown, the point

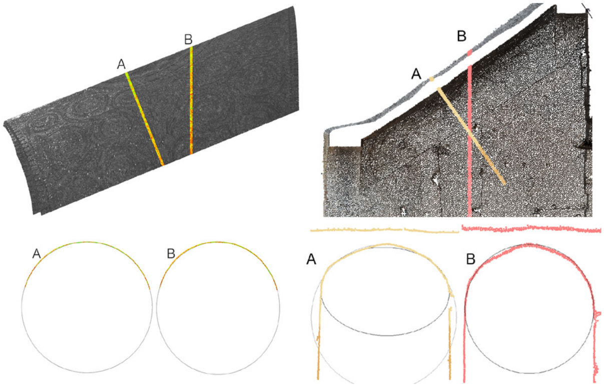


Fig. 10. Inclined vaults of the Palatine Chapel (left) and of the Colosseum (right). Sections perpendicular to the axis (A) and vertical sections (B) with extraction of geometric profiles (elaboration by the authors).

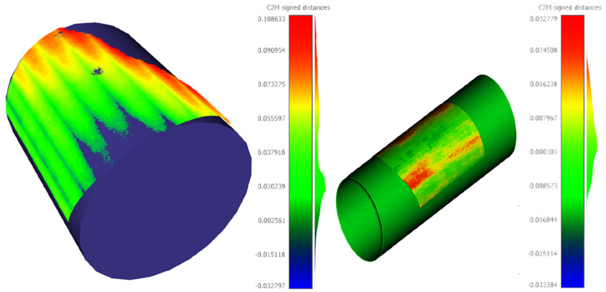


Fig. 11. Visualization of the distance between the cylinder and the point cloud. Left: the cylinder calculated using shape detection algorithm.; right: the one using best fit algorithm (elaboration by the authors).

cloud was first intersected with a vertical plane and then with a plane perpendicular to the crown, in order to analyze the two resulting profiles.
This analysis highlights a particularly interesting element: the section perpendicular to the crown is circular, whereas the vertical section is elliptical, with the minor semi-axis corresponding to the radius of the cylinder (2.61 m) and the major semi-axis, equal to the vault's vertical rise, measuring 2.81 m. This configuration, already noted by Raabe, Trautz and Di Pumpo [2019], deviates from a constructional tradition based on designing the inclined barrel vault as the translation of a semicircle contained in a vertical plane along an inclined axis, thereby generating an inclined cylinder [Adam 2014, pp. 189-211].
As a purely demonstrative comparison, the same analytical method was applied to one of the inclined vaults of the Flavian Amphitheatre [6] to verify the actual peculiarity of the system adopted in Aachen. This investigation clearly showed the use of an oblique cylinder as its geometric genesis (fig. 10).
This peculiarity inevitably raises questions about the organization of the construction site and the preparation of the centering needed for its realization. Leaving aside constructional aspects for the moment, the following phase modeling concerned the reconstruction of the solid with an axis inclined by 21.52° with respect to the horizontal and a circular base, that is, a right cylinder. The reconstruction of the theoretical cylindrical shape from the point cloud can be carried out either semi-automatically –through shape detection and best-fit algorithms– or manually. In this case, the first approach was preferred, since the apparent morphological correspondence between the segmented points and the reference theoretical shape encouraged the adoption of a method capable of producing the statistically most appropriate reconstruction, avoiding additional subsampling steps.
Nevertheless, the shape detection algorithm for the cylinder [7] did not produce satisfactory results. In fact, it further subdivided the already segmented point cloud into smaller portions, calculating a distinct theoretical cylinder for each. This behavior is attributable to constructional deformations of the vault, which are reflected in the point cloud and hinder the identification of a single cylindrical surface. By increasing the tolerance in the deviation between the reconstructed theoretical shape and the corresponding points, the algorithm is able to generate a single solid, approximating the cylindrical surface of the vault while minimizing local errors. However, the theoretical cylinder thus obtained showed significant deviations from the point cloud, incompatible with the constructional irregularities observed.
The second attempt at automated shape reconstruction employed a best-fit algorithm [8] [Bianchini, Carnevale, Griffo 2024]. The algorithm used is iterative in nature, with the objective function defined by the characteristic parameters of the general function of a right

cylinder with axes not parallel to the Cartesian axes (components of the direction vector, axis position, and radius value). This procedure, carried out in the *Matlab* environment, favors a single global solution for the reconstruction of the shape rather than multiple detailed local fittings (fig. 11).
Starting from the theoretical cylinder constructed using the best-fit algorithm, the final phase of the study focused on identifying its characteristic elements, namely the position of the axis, the radius of the transverse section, and the ellipse of intersection with the vertical plane (fig. 12).
Having identified the right cylinder as the most suitable geometric model to approximate the inclined barrel vault, it is now appropriate to examine the practical implications of this choice, particularly with regard to the design of the temporary works. The vault, constructed with greywacke and travertine blocks of heterogeneous shape and size, displays a coursed masonry pattern, in which regular courses of thin, elongated blocks alternate with larger squared elements (fig. 1d). This textural arrangement necessitates the use of a wooden centering, the original configuration of which is not easily reconstructed.
Assuming a fully vertical centering with its base coinciding with the cylinder's diameter would result in a guiding curve with an elliptical profile. By contrast, employing a semicircular arch centering would require it to be inclined perpendicular to the springing plane. Both scenarios imply a notable complication of conventional construction practice, likely driven primarily by the deliberate intention to realize a right cylindrical geometry.
Raabe, Trautz and Di Pumpo [2019, pp. 26-29] propose a construction model based on the use of a movable centering, slightly smaller than the vault diameter and horizontally shifted by approximately 10 cm between the two sides. According to the authors, this procedure would account for the formation of an elliptical arch arranged on the vertical

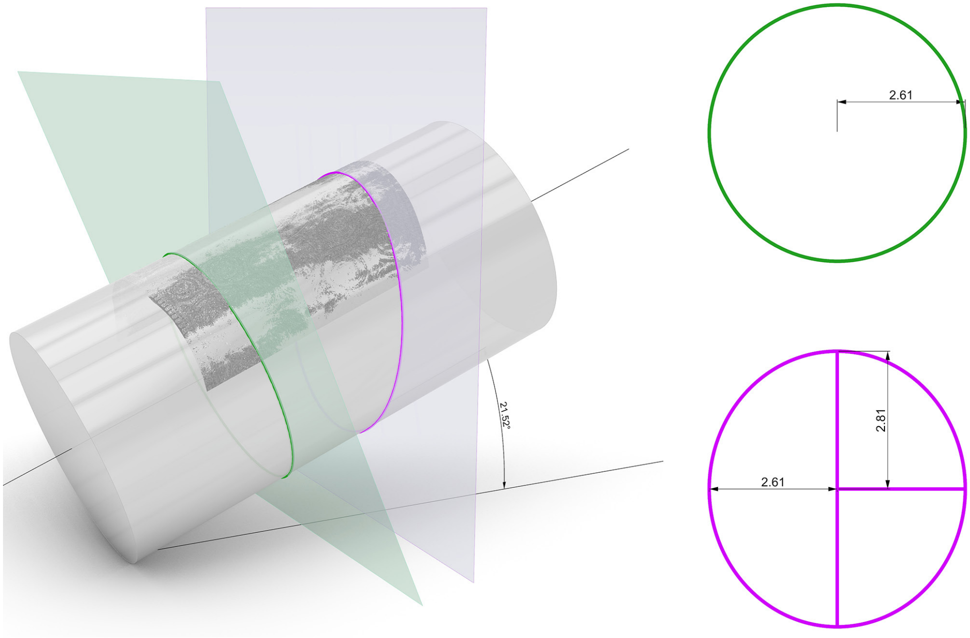


Fig. 12. Left: the theoretical cylinder (in gray), the vertical plane (in purple), and the plane perpendicular to the axis (in green); right: representation of the two intersection curves (elaboration by the authors).

plane. However, this operational principle would produce a flattened elliptical arch, in contrast with the high-rise profile indicated by the analysis of the vault's vertical tracing.
Ultimately, synthesizing the various experimental observations, it becomes evident that the builders possessed a profound understanding of the geometric properties of conic sections, as well as the ability to translate this knowledge into practical construction solutions.

Analysis of results

In recent decades, the evolution of 3D survey methodologies has marked a fundamental milestone in the history of representation, opening new scenarios for the documentation and interpretation of architecture. Today, we are witnessing a further phase of this development: attention is no longer focused solely on data capturing and processing techniques, but increasingly on their analytical potential. Thanks to the high degree of accuracy they can achieve, point clouds do not merely represent a faithful record of reality; they become the raw material for experimenting with tools capable of interpreting them in a manner consistent with their nature.
From this perspective, the case of the Palatine Chapel has provided an opportunity to explore the various strategies currently available, with the aim of fully conveying the informational value of the collected data. From the application of shape detection and best-fit algorithms to the use of more traditional mathematical modeling, the range of possibilities demonstrates that the study of architectural history can no longer disregard advanced analytical approaches. These tools not only allow us to address well-established questions but open the door to new inquiries and perspectives, revealing unexpected aspects that architectural construction inherently preserves.

Conclusions

Within the broader framework of the *Aachen Cathedral Project*, the present study represents a further step in the investigation of the geometries emerging from the analysis and interpretation of the metric data collected on the Palatine Chapel.
The evidence presented, whose reliability is firmly anchored in the accuracy of the original data and the rigor of the applied analytical methodology, reveals an unexpected mastery of conic geometry –an expertise that stands in marked contrast to the state of Western geometric thought as transmitted through historical texts. This characteristic also carries significant architectural implications, reinforcing the hypothesis that the Palatine Chapel was conceived as a unified design and meticulously controlled at every stage. In this context, the presence of a single, talented architect identified in the sources as Odo of Metz, appears both a sound and reasonable hypothesis.
The compositional analysis of the building further highlights several original features, as exemplified by the dynamic relationship established between the ambulatory bands and the void of the central octagon. At the first level in particular, there is an alternation of open quadrangular sectors and blind triangular wedges, which appear to be vaulted with right circular cylinders and conical surfaces, both inclined.
These peculiarities, from both a constructive and formal standpoint, suggest a connection with Eastern building traditions [Raabe, Trautz, Di Pumpo 2019], and specifically with Armenian models [Bianchini 2024]. This comparison, combined with the historiographical hypothesis attributing the same origin to Odo of Metz, seems to outline a coherent picture: an architect of exceptional talent conceiving the Palatine Chapel as a unified project, integrating Roman and Byzantine elements while simultaneously referencing his own cultural background. In doing so, Odo demonstrates not only full mastery of architectural forms but also a level of geometric knowledge that is strikingly advanced in comparison with what is conventionally acknowledged in historiography.
The case of Aachen thus reinforces the idea that, during the so-called 'dark Ages', medieval Practical Geometry served as the primary locus for the preservation and development of Western geometric thought, rather than merely providing basic constructions for key sectors such as building, urban planning, or defense [Bianchini 1995]. The vaults of the Palatine Chapel offer a first significant indication of this, although they have so far received limited attention within the historiographical framework, which has tended to privilege written sources while overlooking the fact that knowledge transmission occurred primarily through oral instruction and apprenticeship. Hence arises the hypothesis of an alternative history of medieval geometry –one not recorded on parchment but inscribed in stone, now ready to be revealed through the analytical, measurement, and simulation tools available to us today [9].

Notes

[1] The *Aachen Cathedral Project* is an international research initiative involving Sapienza Università di Roma (Carlo Bianchini, Carlo Inglese, Guglielmo Villa, Martina Attenni, Marika Griffo, Roberto Barni), Robert Gordon University in Aberdeen (Douglas Pritchard), and RWTH Aachen University (Yannick Ley), in partnership with the Dombauhütte of Aachen cathedral (Jan Richarz). The aim of the project is to provide the most comprehensive possible documentation of the cathedral's buildings and their constituent materials through the integrated use of advanced surveying technologies. The project is co-funded under the framework of the Italian National Recovery and Resilience Plan (PNRR), Extended Partnership 5 'CHANGES', Spoke 8, Thematic Line 1: Production, Organization, and Communication of Knowledge, coordinated by Prof. Carlo Bianchini.

[2] The elevation map in *Autodesk ReCap* allows the assignment of a color value to each point of the point cloud according to its height relative to a reference axis. This tool does not generate an independent metric analysis but provides a color-coded representation that facilitates the visual identification of height variations or local deformations.

[3] A direct examination of the stone was not possible, since all the original structures at both the lower and upper levels are covered by Hermann Schaper's 20th-century mosaic [Radel 2022]. However, it is reasonable to assume that these interventions did not significantly alter the original geometries and proportions of the underlying structures.

[4] The decision to verify the correspondence between the survey data and the surfaces of these conoids, beyond purely geometric considerations, also considers their (much later) probable use for constructive purposes. Reference is made to the shipwright's circular wedge studied by John Wallis –known as Wallis's *cono-cuneus* [Wallis, 1648] – and to the cone terminating in a line described by Guarino Guarini [Guarini 1671, tr. XXV, theor. 1, prop. VIII; Guarini 1737, cap. IV, oss. 6]. In both cases, the surfaces can be classified as conoids with a plane directrix; however, unlike the one examined in the present study, their circular directrix is perpendicular to the horizontal springing plane, which defines the orientation of the director plane.

[5] The analysis was carried out using the geometric features computation tool integrated in *CloudCompare* v2.13.

[6] The point cloud originates from 3D survey and HBIM modeling activities coordinated by the Archaeological Park of the Colosseum (Project Manager: Dr. Federica Rinaldi). The work was carried out by the awarded temporary consortium led by CFR (Consorzio Futuro in Ricerca), Ferrara (scientific coordination: Marcello Balzani, Guido Galvani, Fabiana Raco), in collaboration with GEOGRA' Srl (Sermide), ETS Srl, and JANUS Srl (Rome).

[7] For the experiment, the RANSAC Shape Detection plugin integrated in *CloudCompare v2.13* was used.

[8] The cylindrical best-fit algorithm in the *Matlab* environment was developed and tested within the context of Flavio Carnevale [Carnevale 2026].

[9] In agreement with the arguments presented, Carlo Bianchini was responsible for drafting the *Introduction* and *Conclusions* sections; Martina Attenni was responsible for drafting the sections *The Palatine Chapel*, *Research objectives* and *Geometric genesis of the groin vaults*; Marika Griffo was responsible for drafting the sections *Geometric genesis of the Conical vaults*, *Geometric genesis of the inclined barrel vaults* and *Analysis of the results*.

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Fit Structures. The Representation of Bridge and Viaduct Design in the Work of Silvano Zorzi

Gianluca Capurso

Abstract

This paper presents the results of an investigation into the use of graphic representation in the design of bridges and viaducts within the work of Silvano Zorzi, a central figure of the twentieth-century Italian School of Structural Engineering. The study was carried out within the framework of the SIXXI research project – XX Century Structural Engineering: the Italian Contribution *(ERC Advanced Grant, PIs: Sergio Poretti, Tullia Iori).*
Its aim is to highlight the role of drawing as a means of making visible the internal logic of the designed structure and, in particular, the coherence between form, structural behaviour, and construction process. The analysis is based not only on the available literature but, above all, on documentation preserved in the Zorzi Archive at the Politecnico di Milano and in numerous other archives belonging to clients and construction firms. Through these materials, the essay investigates how Zorzi, as a structural designer, employed representation –from the preliminary sketch to the executive detail– not only as a critical tool for control, used to describe and validate technical solutions, but also as a means of expressing the logic, at once rational and aesthetic, that governs structural form.

Keywords: history of structural engineering, infrastructure, viaducts, building sites, reinforced concrete.

Introduction and state of the art

Silvano Zorzi (Padua 1921 - Milan 1994) is one of the foremost masters of the Italian School of Structural Engineering. Within its history –reconstructed as part of the *SIXXI* research project [1]– he stands out for his identity as an engineer-designer, one who conceives and draws structures, particularly bridges, with essential lines: works designed at the scale of the landscape and harmoniously integrated into their environment. To achieve the extraordinary formal quality of his works, he exploited the full potential of construction materials, dedicating himself from the outset to reinforced concrete, and, in particular, to its prestressed version. In this way, he created elegant structures with slender profiles that span rivers and roads with spans seemingly incompatible with the dimensions of their piers and decks [2].
This paper proposes an enquiry into the use of graphic representation in relation to some of his most significant works, based on largely unpublished graphic and photographic material preserved in the Zorzi Archive at the Politecnico di Milano, and in numerous other archives of clients and construction firms, as well as on the existing bibliography concerning the engineer's work. The analysis developed in this article is limited to the design of bridges and viaducts, which represent the most significant part of Zorzi's professional activity [Zorzi 1981; Iori, Capurso 2019] and focuses on the connection between graphic representation, static conception,

and construction logic. The latter aspect, in particular, has not been specifically examined in the scientific literature. In the executive drawings, one can thus see the evolution of Zorzi's approach to infrastructure design over the various phases of his long career, highlighting the role of graphic representation as a means of making visible the design logic of the structure, and particularly the coherence between form, structural behaviour, and construction process.

Design and construction

For the protagonists of the Italian School of Structural Engineering, drawing played a role intimately connected with construction and with their inventions. Pier Luigi Nervi (1891-1979) used it not so much to represent the final result as to explain to the workers of his company, Ingg. Nervi e Bartoli, how to produce in practice the thousands of small elements of his original construction system, based on structural prefabrication and ferrocement, with which he assembled the magnificent domes that made him famous throughout the world. The drawings of Riccardo Morandi (1902-1989) went into such detail on the positioning and locking of prestressing cables, with loops and sinuous curves, that one could almost perceive their tension already on paper, as later in his distinctive cable-stayed frames. Sergio Musmeci (1926-1981), for his part, found it difficult to represent in plan, elevation and section his 'formless forms', which rejected known typologies and were born first as soap bubbles, then as physical models, and only in the end were transposed onto the drawing sheet.
And in Zorzi's case?
In what way did the control and verification of structural form afforded by graphic representation enable his practice, and later his company In.Co. - Ingegneri Consulenti, to ensure the high technical and formal quality of his works?
In 1983, the journal *Casabella* published an article written by Zorzi himself on the elevated road for the state highway Pontebbana, introduced by a commentary by Giacomo Polin (1956) [Zorzi 1983]. To accompany his presentation effectively, Zorzi included five cross-sections of bridges (fig. 1) –simple, schematic sketches– illustrating the direction of his formal and technological research in viaduct design: from the most conventional prefabricated beams on massive, constant-section piers, through increasingly light and essential solutions, to the minimal monolithic plate, with a section smoothly merging into the pier, the very solution chosen for the Pontebbana viaduct. However, it is not the sketches that dominate this unusual article in a learned architectural journal, but the technical drawings: road layouts, profiles and gradients, construction sections comparing the ordinary solutions forming the basis of the tender with those later designed and realised by Zorzi, and above all, construction schemes illustrating ingenious site procedures made possible by the use of innovative equipment. Alongside fine photographs of the site and the completed work, these drawings fill the pages, bearing witness to both the contemporary architectural culture's interest in structural conception and the intimate connection between graphic representation and construction in Zorzi's practice.
Thus, by analysing not so much the conceptual sketches as the working drawings developed by his highly skilled partners –from Giorgio Macchi (1930-2023) to Sabatino Procaccia, Lucio Lonardo and Aldo Muller– who co-signed numerous projects with Zorzi and accompanied his name in presentations published in specialist journals, it becomes clear that Zorzi's graphic production must be considered inseparable from that produced by his studio and, later, by In.Co.

Bridges in the landscape

Forced to abandon his studies during the Second World War, Zorzi took refuge in Switzerland, where he became a pupil of Gustavo Colonnetti (1886-1968) and later graduated at the end of the conflict. He was thirty-five when, together with the construction firm Rizzani, he won the design-and-build competition for the first major bridge of the Autostrada del Sole – the structure crossing the river Po at Piacenza, in the locality of Mortizza (fig. 2). Completed in March 1959, the bridge is a simple structure: sixteen reinforced-concrete beams, each with a span of seventy-five metres, prestressed using the BBRV system imported from Switzerland, simply resting on the piers.
The construction drawings describe in meticulous detail the geometry of the piers and beams and the arrangement of the prestressing cables, but the dossier also includes an overall perspective view of the bridge, certainly prepared by a studio collaborator. These graphic studies allow verification of the visual relationship between the structural parts –piers and girders– and of the overall effect produced by the succession of equal spans, while the riverbank vegetation in the background is only lightly suggested.

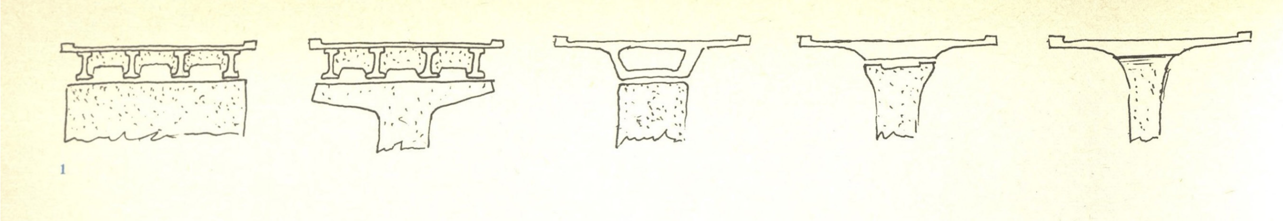

Fig. 1. Schemes of cross-sections for viaducts (Historical Archive of the Politecnico di Milano, Silvano Zorzi Collection, Milan).

Fig. 2. Bridge over the river Po, working drawings. Perspective view (ANAS Historical Archive, Cesano).

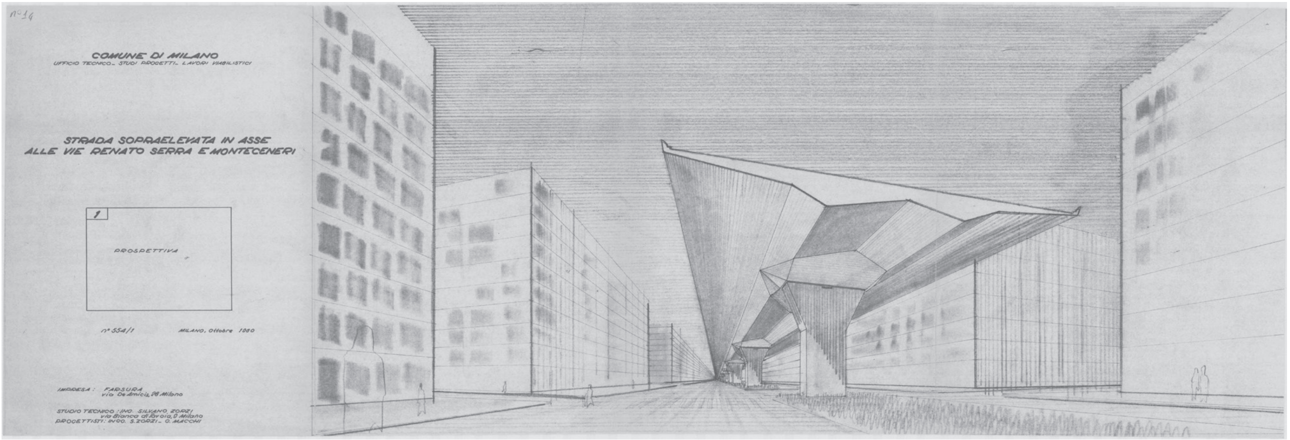

Fig. 3. Elevated road along viale Renato Serra and viale Monte Ceneri, working drawings. Perspective view (Municipal Archive of Milan, Technical Infrastructure Department, Milan).

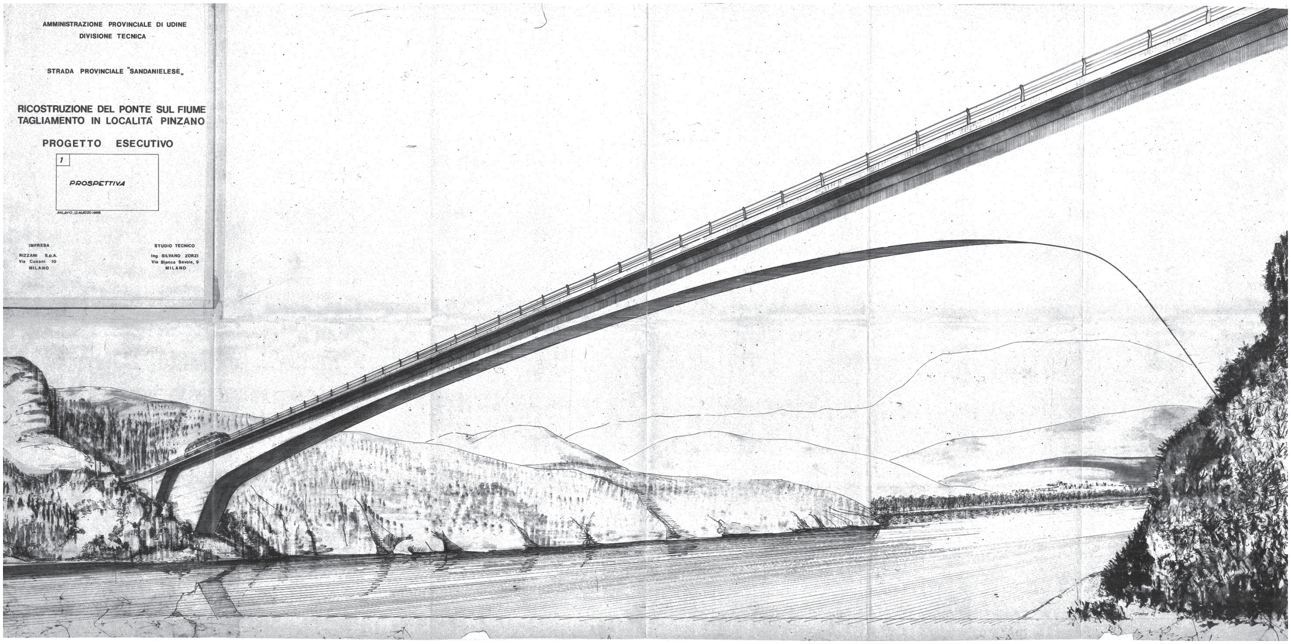

Fig. 4. Bridge over the river Tagliamento at Pinzano, working drawings. Perspective view (In.Co. S.p.A. Historical Archive, Rome).

The frequent use of perspective views, perhaps required by contracting authorities for project assessment, also reveals Zorzi's attention to verifying the soundness of his formal solutions. Perspectives were therefore prepared by the Studio and later by In.Co. for public selection procedures; they often depict low-angle or lateral viewpoints, foreshortened and close-up. The perspective accompanying the executive drawings of the elevated roadway in Milan between viale Renato Serra and viale Monte Ceneri (1960) emphasises the articulated composition of the surfaces of the pier and of the underside of the deck (fig. 3) and introduces a refined plan view showing the arrangement of the timber formwork boards, whose imprint would economically be left visible. This work was conceived not only to carry vehicular traffic along its deck but also to be viewed from below, at pedestrian level. The perspective that opens the executive dossier for the bridge over the Tagliamento at Pinzano (1968-1969), updating the version presented for the design competition, analyses the perception of an observer standing on one bank of the river and highlights the elegance of the portal-arch line (fig. 4).
A perspective view at the opening of the dossier was also chosen to illustrate the visionary project for the bridge of Guayllabamba (1968), prepared for submission to the competition called by the Ministry of Public Works of Ecuador for the *Carretera Panamericana Quito-Tulcán*, and developed in collaboration with Lonardo (fig. 5). The bridge was conceived as a stretched ribbon of prestressed reinforced concrete, only thirty centimetres thick, suspended between the two banks, three hundred metres apart, shaped to the geometry of a catenary with a small sag. Its behaviour was then described in the other drawings –plan, elevation, and section– included in the competition dossier. According to these graphical studies, which represent with convincing realism a structure probably impossible to build, the deck, formed by sheathed cables subsequently grouted to constitute both reinforcement and prestressing tendons, was to be completed in segments, cast using a

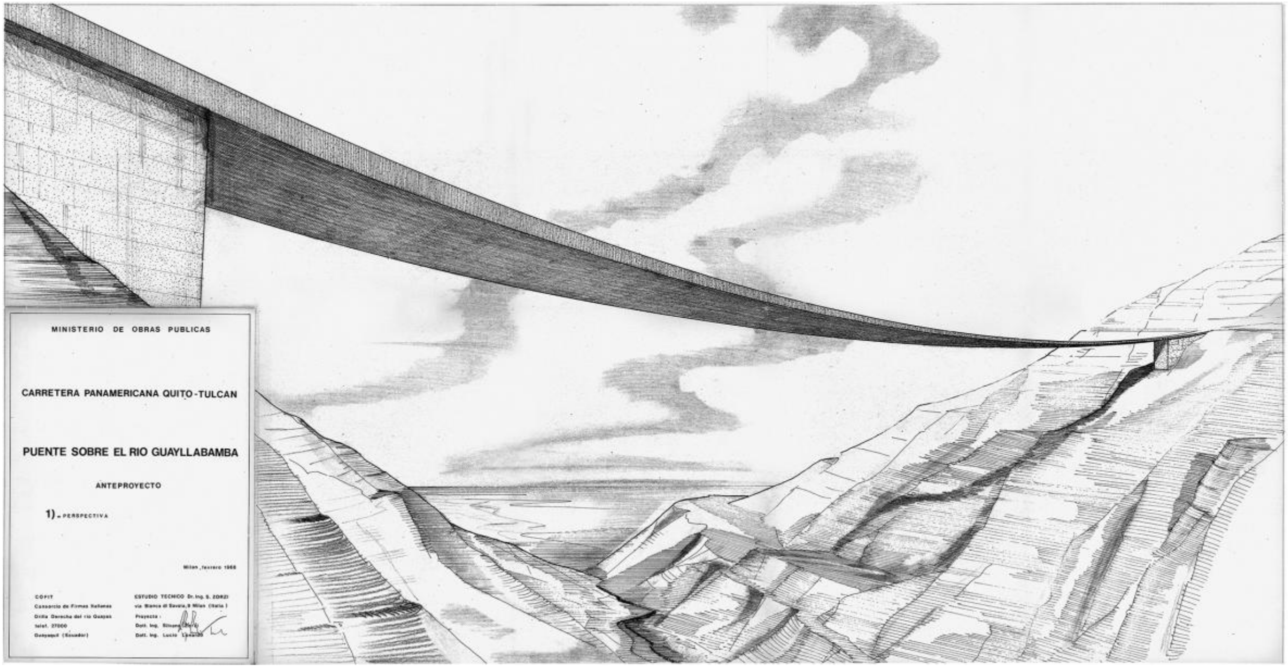

Fig. 5. Bridge over the river Guayllabamba, competition project. Perspective view (Historical Archive of the Politecnico di Milano, Silvano Zorzi Collection, Milan).

special centring and later prestressed transversely [Capurso, Martire 2017, pp. 98-115].
Thus, perspective drawings of bridges –far from common in the archives of structural engineers– emphasise, through deliberate chiaroscuro and shading, the edges and boundaries, enhancing the graphic essentiality of the works, often reduced to a few juxtaposed elements. They resemble presentation drawings of a lamp or a bookcase rather than those of a functional and 'brutal' work such as a viaduct.

Drawing for calculation and assembly

In Zorzi's work, drawing also served as a tool to support analytical calculation. In 1961, for the completion of the route of the Autostrada del Sole, he designed two further bridges, this time arches, both over the Arno and both built by the Astaldi company, at Incisa and at Levane.

For the first bridge, he combined two portal arches in prestressed reinforced concrete, each with a span of 104 m, constructed on spectacular scaffolds of Innocenti tubes. The analysis of stresses was conducted through the plotting of influence lines of the hyperstatic unknowns, using the method of the ellipse of elasticity (fig. 6). The calculations were developed analytically, but their graphic representation allowed a verification of the coherence and consistency of the values, which was also useful for the approval of the design by the competent authorities. The verification of the foundations, moreover, was carried out using a genuinely graphic method, through the funicular polygon. This mixed approach to calculation, both analytical and graphical, would be adopted by Zorzi throughout his career, reappearing in the dossier for the Gorsexio viaduct in Liguria, built in the mid-1970s.
The bridges at Incisa and Levane were among the last arch bridges built for an Italian motorway route. The reasons are

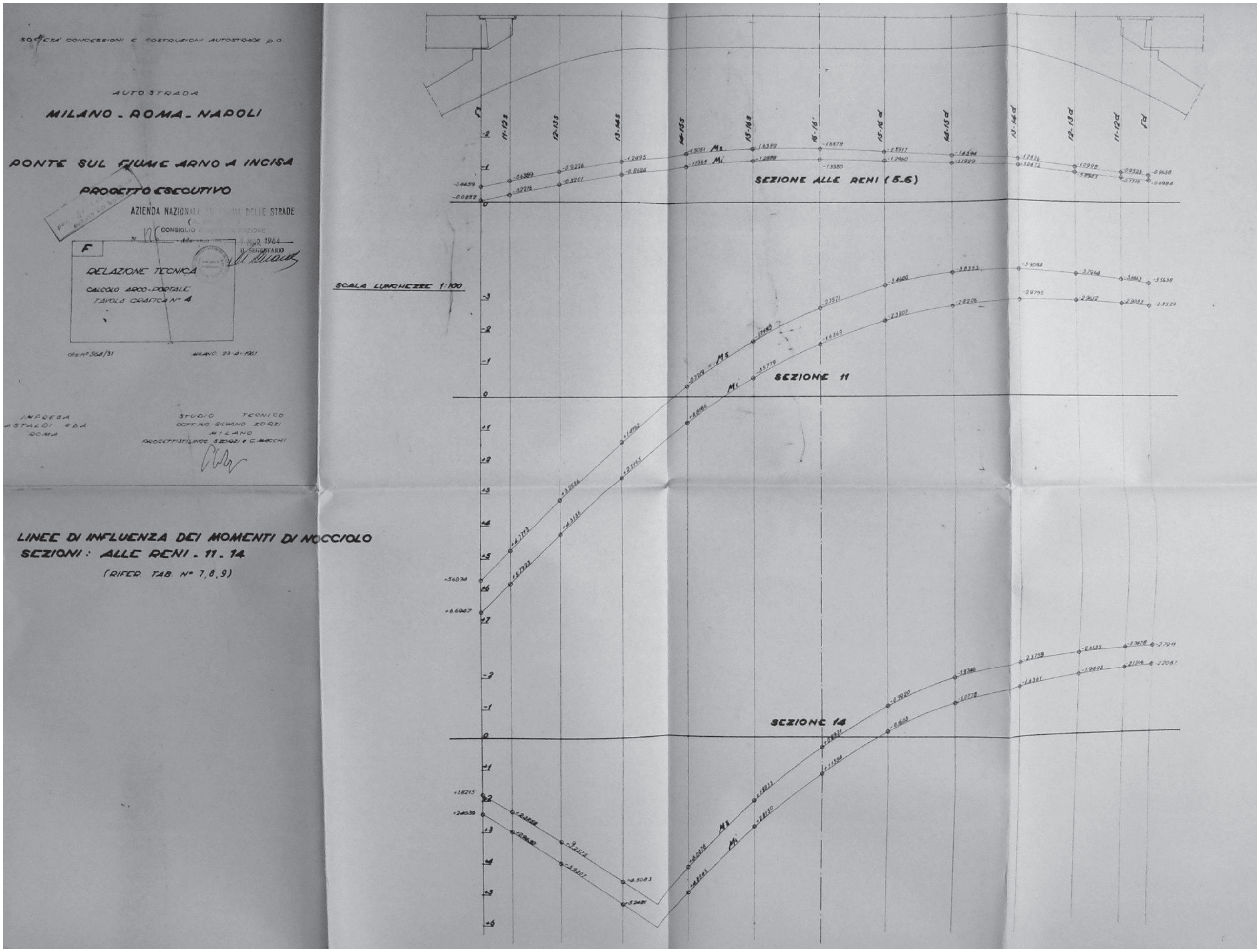

Fig. 6. Bridge on the Autostrada del Sole at Incisa. Calculation of influence lines, diagram (ANAS Historical Archive, Cesano).

numerous: new anti-seismic regulations discouraged thrusting structures; the Superintendencies for Cultural Heritage began to consider the arch bridge too 'intrusive' in the landscape and demanded more abstract, linear and slender solutions; the rising cost of labour made the erection of centring increasingly expensive; and finally, Italian public-works policy demanded ever faster construction schedules and greater site productivity. The artisanal character of the final years of large arch bridges thus gave way to the need to construct ever more rapidly a great number of viaducts for the motorway sections granted in concession during the 1960s and built throughout the following decade.
The emergence of this new type of viaduct, with tall piers and continuous decks, did not find Zorzi unprepared.

Fig. 7. Bridge on the Autostrada del Sole at Incisa, under construction (In.Co. S.p.A. Historical Archive, Milan).

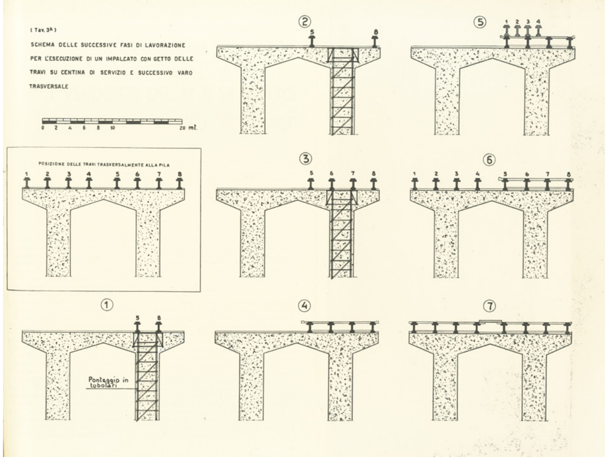

Fig. 8. Bridges on the Autostrada del Sole at Mugello, construction phase diagram (SIXXI Archive).

Rather than merely adapting to the new production requirements, the engineer devoted himself to inventing new construction procedures. In his projects, the methods of assembling the structural elements –which would form the decks of the viaducts– assumed a central role.
During the 1960s, Zorzi was also an active disseminator of technical knowledge, giving invited lectures and writing articles for specialist journals such as *Autostrade* and *L'Industria Italiana del Cemento*. In illustrating the construction techniques adopted for the Mulinaccia, Bellosguardo, Baccheraia, Goccioloni I and Goccioloni II viaducts on the Autostrada del Sole (sections V and VI of the Florence area, 1959-1960), the engineer used, alongside site photographs, graphic diagrams evidently derived from the project drawings, which communicated both the structural characteristics and the innovative erection procedures employed (fig. 8).
Thus, beyond depicting the arrangement of the reinforcement, the prestressing cables, and the shape of the cable-head housings within the beams, drawing was also used to illustrate the 'sequence of elementary operations for the launching' of the viaduct beams. Two distinct versions were developed for different parts of the infrastructure: one foreseeing a prefabrication yard with transport on trolleys, and the other involving casting of the beams on a service centring supported by the already completed structures, followed by transverse launching – an invention by Zorzi and the construction company to overcome the lack of space for setting up a prefabrication yard.

Drawings for mobile workshops

Prefabrication might seem, at first glance, to leave little room for design or for research into the expressive potential of structural form. During these years, however, Zorzi devoted himself to reinventing the construction site, managing to design new masterpieces [Zorzi 1968]. Distinguishing himself from his contemporaries, Zorzi declared: "The work to be realised must indeed be the most functional, but at the same time it must also take shape as a harmonious and lasting insertion into the environment and constitute a vision that is satisfying in itself" [Zorzi 1981, pp. 11-12]. Only by rationalising and industrialising the construction site could Zorzi recover, within this new context, the quality and flexibility of in-situ casting, which he was unwilling to abandon. He thus introduced into Italy two special machines, imported from Germany but adapted for Italian construction: the self-advancing centring and the launching girder.

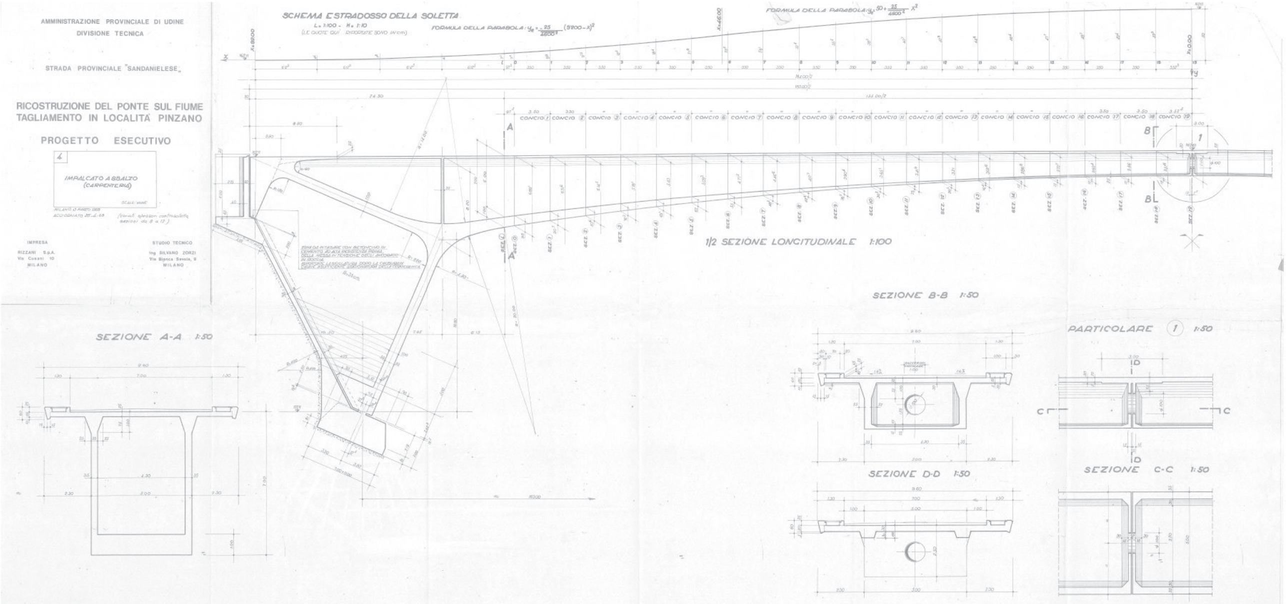

Fig. 9. Bridge over the river Tagliamento at Pinzano, working drawings. Cantilever deck, longitudinal section of formwork (In.Co. S.p.A. Historical Archive, Rome).

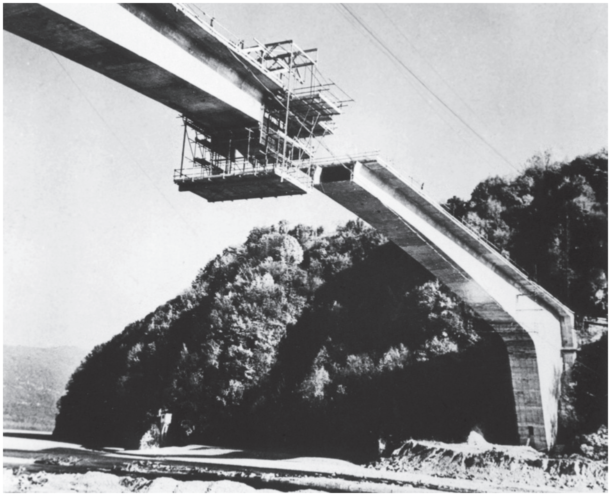

Fig. 10. Bridge over the river Tagliamento at Pinzano, under construction (Historical Archive of the Politecnico di Milano, Silvano Zorzi Collection, Milan).

Fig. 11. Gorsexio viaduct at Voltri on the Voltri-Alessandria motorway (Historical Archive of Cooperativa Muratori & Cementisti C.M.C., Ravenna).

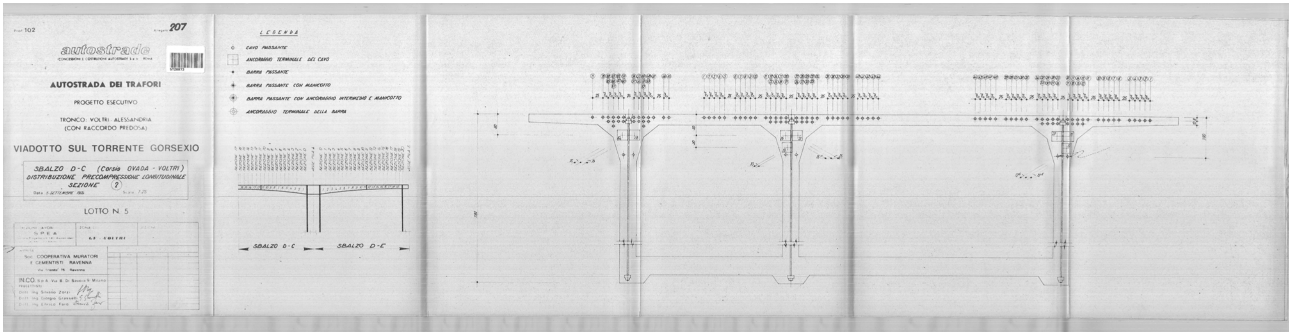

Fig. 12. Gorsexio viaduct at Voltri on the Voltri-Alessandria motorway. Working drawings, cross-section (Historical Archive of Cooperativa Muratori & Cementisti C.M.C., Ravenna).

The first was a small, covered, mobile workshop, resting on the heads of the piers and sliding forward from one pier to the next [Blandino 2014, pp. 104-113]. Its use was advantageous when the piers were all identical, as in urban viaducts and elevated roads built outside city centres. In these cases, too, the elevated roadway was conceived like a portico: the intrados had to be beautiful, since it was to be appreciated from below. Zorzi was skilled at designing slender, sculpted piers that stood at the centre of a deck slab opening in cantilever, thinning elegantly toward the edges. For the construction of such works, among which the Teccio viaduct at Cadibona on the Turin-Savona motorway (1974) stands out for its audacity, Zorzi's office was involved not only in architectural and structural design but also in defining the operation of the machines themselves. The drawings, developed in collaboration with specialist firms, analysed and validated the assembly and advancement schemes of the equipment used, which became crucial to the successful execution of the works.
With the launching girder, by contrast, Zorzi built bridges using the 'little by little' technique. Unlike the unitary image of the completed structure, the working drawings had to specify the size of the segments to be cast –designed so that they could be supported by the construction machine until the concrete reached sufficient mechanical strength– as well as the type and layout of the prestressing bars, by then almost always of the Dywidag type. Zorzi adopted launching girders for the first time in 1967, for a series of viaducts along the Azzurra motorway in Liguria, from Genoa to Rapallo, and later for the aforementioned bridge over the Tagliamento at Pinzano (figs. 4, 9, 10). The analyses in elevation, plan and section show the distinctive constructive solutions defined by Zorzi: the careful modelling of the concrete members, the point-by-point layout of the bars, the special devices devised to obtain the hinges at the crown of the bridge, and the three-hinged configuration that ensured the structure's exceptional line. Using the same technique, he built the deck of the Gorsexio viaduct (figs. 11, 12), one of his final masterpieces. Rising on vertiginous piers with lamellar sections, the definition of the construction phases demanded sustained effort from the studio's draughtsmen: twenty meticulously detailed sections were needed for each half-span to describe the exact position of all devices required for prestressing – through cables, anchorage systems for continuous bars, with couplers or intermediate anchorages, and terminal anchors whose position varied continuously within the beam. This minute and refined technological design reveals Zorzi's persistent attempt to preserve in his works his distinctive minimalist character and the structural, constructive, and figurative lightness typical of his design approach.
Zorzi was aware of the anachronism of his position. At the beginning of the 1980s, when issues of formal quality and the environmental permanence of works remained unresolved in Italian infrastructure projects, he remarked that the responsible designer –one who cared for the essential expression of structure and its proper execution– in a "climate of great competitiveness and in the face of mostly inattentive clients", would, unfortunately, "often find himself alone" [Zorzi 1981, p. 35].

Conclusions

The analysis of project representation in the work of Silvano Zorzi reveals how drawing served as a critical device capable of making visible the intimate connection between structural logic, construction process, and formal quality. In the design of bridges and viaducts, the graphic documents do not merely record technical solutions; rather, they embody a design approach that integrates calculation, the definition of assembly procedures, and the perception of the structure as an object situated within the landscape. In this sense, Zorzi's graphic production stands in continuity with the tradition of the Italian School of Structural Engineering, while also representing an original evolution of it – one oriented towards reconciling the demands of industrialised construction with a sensitivity to the relationship between structural form and its environmental or urban context.
Project representation in Zorzi's practice should therefore be understood not only in terms of technical experimentation but also as the construction of a visual language, new within the panorama of Italian infrastructure design, and based on affinities with the world of industrial design. His work further demonstrates how, in the best tradition of post-war Italian engineering culture, representation cannot be reduced to mere transcription but constitutes a genuine instrument of invention, control, and communication of structural form.

Acknowledgements

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Notes

[1] On the research project SIXXI – XX Century Structural Engineering: The Italian Contribution (ERC Advanced Grant 2011. PIs: Professors Sergio Poretti and Tullia Iori), see: https://www.tulliaiori.com/SIXXI/. On the Italian School of Structural Engineering and its masters, see the series SIXXI – Storia dell'ingegneria strutturale in Italia, edited by S. Poretti and T. Iori, published by Gangemi between 2014 and 2020.

[2] For the profile of Silvano Zorzi as a structural designer and for his professional career within the broader history of twentieth-century Italian engineering, see Iori, Poretti 2015 and Iori, Capurso 2019.

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Dimensioning and Geometric Patterns in Hadrianic Architecture: the Case of the Temple of Venus at Baiae

Enrico Gallocchio, Elena Eramo, Silvia Bertacchi, Filippo Fantini

Abstract

The so-called Temple of Venus at Baiae (2nd century A.D.) is one of the most extensive and complex surviving Hadrianic composite vaulted architecture. Although traditionally identified as a temple, the building was in fact part of the Baian thermal complex. Its spatial configuration reflects the experimental character typical of Hadrianic design.
This study, based on an integrated survey, investigates the geometrical logic underlying its plan and elevation. The analyses focus on whether the composition was governed by a modular grid in plan and elevation, with diameters set as multiples of seven and articulated through the ad quadratum scheme. Reverse modelling protocols and best-fitting algorithms were applied to the polygonal model of the rotunda to test these hypotheses. The results confirm a design diameter of 91 pedes*, with a modular subdivision of 13 pedes, consistent with other Hadrianic domes. In elevation, the vault appears as composite "umbrella" dome made up of alternating cylindrical segments and trikentron surfaces, creating a coherent vaulted system. The unusually slender proportions (1:8.86 diameter-to-thickness ratio) highlight the structural audacity of the monument. The research demonstrates how Hadrianic architecture employed flexible geometric tools, –multiples of seven, ad quadratum, and modular grids– not only for design efficiency but also to generate innovative spatial solutions. These findings contribute to the broader understanding of Hadrianic experimentation.*

Keywords: Hadrianic domes, modular grid design, trikentron, reverse modelling, Roman vaulted structures.

Introduction

Among the surviving examples of Hadrian's composite vaulted architecture (2nd century A.D.), the so-called Temple of Venus in Baiae, Naples, is one of the largest structures, although the vault has only partially survived the centuries.
The architecture of the complex [De Angelis d'Ossat 1977; Rakob 1988] is dominated by the large volume of the main hall, with a central plan and covered by a monumental composite vault (figs. 1, 2). Around this nucleus, a series of small subsidiary volumes defines an approximately square basement, today mostly underground. On the western side, two additional volumes are attached, reduced in scale and architecturally subordinate to the central body. The function and configuration of these spaces remain uncertain, and their legibility is compromised not only by the overall poor state of preservation but also by the construction of a modern road that has obliterated part of the original layout (fig. 3).
Although traditionally referred to as the 'temple', the building was in fact a thermal facility. The improper designation as a temple is misleading, as its architectural configuration reflects the experimental character typical of constructions commissioned by Emperor Hadrian and possibly partly designed by him, where conventional typologies were frequently reinterpreted. The present study is based on data acquired through integrated surveying, aimed at producing a high-resolution three-dimensional model to be used as the basis for the geometrical analysis of the design.

The research forms part of a broader research project, focusing on the architectural and structural peculiarities of Hadrianic domes [Cipriani et al. 2020, Eramo, Fantini 2024; Roca et al. 2024]. Within this framework, the authors have developed a methodological approach that begins with an analysis of the building's overall planimetric composition and proceeds through a progressively refined investigation of the elevations. In addition to the use of applications intended for the formal reading of the remains, the method incorporates the theoretical apparatus derived from Vitruvian exegesis with the mathematical principles articulated by Hero of Alexandria [Heiberg 1914a; 1914b], offering interpretative tools that prove particularly effective in addressing archaeological questions related to design logic, as well as the reconstruction of lost or fragmentary architectural elements.

Fig. 1. The monumental complex of the Temple of Venus from the western entrance (photograph by S. Bertacchi).

Fig. 2. View of the surviving portion of the dome and the openings in the drum (photograph by S. Bertacchi).

In addition to the analyses conducted to interpret and reconstruct the sequence of steps through which the planimetric was translated into the elevation and into the definition of the intrados of the vaulted system, this study integrates the results of recent core samples carried out at the centre of the main hall (fig. 4). These data provided elements for a more accurate understanding of the original elevation and floor level. The study of the elevations indicates the presence of an articulated vaulted system composed of eight main cylindrical segments, set on the externally octagonal drum, and eight *trikentron* [1], double-curved surfaces positioned above the windows.

Notably, the dome under investigation is among the largest known in the ancient world [Sanpaolesi 1971], with a free span of 26.57 metres and a wall thickness of approximately 3 metres at the structural piers located at the corners of the external octagonal perimeter. This results in a diameter-to-thickness ratio of approximately 1:8.86, which is remarkably slender when compared to the Pantheon's dome in Rome, whose 43.56-metre span is supported by 6.2 metres thick walls, yielding a ratio of roughly 1:7.03. These proportions highlight the technical audacity of the Baian structure and reinforce its role as a paradigmatic example of architectural innovation.

Finally, the analysis of the building and vault remains helps to position the Temple of Venus within a broader architectural complex extending up the slope, representing a later expansion, not aligned with the adjoining pre-existing structures.

The following results lay the groundwork for future investigations into the full extent of the complex and its volumetric and design logic, the understanding of which is hindered by the partial ruin of the structures and by ongoing bradyseismic phenomena, opening further perspectives for broader studies on Hadrianic architectural experimentation.

Objectives and methodology

The purpose of this study is to highlight the systems for dimensioning used by the ancient architect as design rules and constraints in both the plan and elevation of

the Temple of Venus complex at Baiae. Through the analysis of reality-based data and historical sources, the authors aim to verify possible proportional relationships between buildings characterized by shapes and structural solutions comparable to those of the Temple of Venus. In particular, the aim is to verify the presence of a modular grid underlying the entire composition, and whether the diameter of the vaulted space is a multiple of 7, in line with the studies of Svenshon [Svenshon 2009], and Fuchs [Fuchs 2023].
Among the objectives of this study is the formulation of a hypothesis regarding the total height of the domed circular chamber, with the aim of verifying the ratio between the building's planimetric layout and its vertical elevation. In several Hadrianic constructions previously analysed – such as the Small Baths [Cipriani et al. 2017], the Eastern Triclinium of the Golden Court, and the *Serapeum* [Eramo, Fantini 2024] at Hadrian's Villa– a 1:1 ratio between plan and elevation has been consistently observed. However, in other cases, the vertical dimension exceeds the horizontal span due to various factors, often of a structural nature, as exemplified by the Vestibule of access to the Golden Court, where the increased height responds to specific engineering and spatial requirements [Adembri et al. 2018].
The shape of the surviving portions of the different segments composing the vault is therefore the subject of a quantitative study, which aims to hypothesize the overall geometry ruling the design of the dome. To this end, a reality-based 3D model derived from data acquired in February 2024 has been created. To ensure reliable data as a foundation for geometric analysis and interpretation, a comprehensive survey of the monument was conducted, including the surrounding area to reconnect the Temple of Venus with the upper archaeological ruins, at present obliterated by the vehicle-accessible road. The survey activities included an integrated documentation, i.e., i) a Terrestrial Laser Scanner (TLS) survey using a Leica ScanStation C5 based on Time-of-Flight (ToF) technology (80 scans at medium resolution) to create a detailed 3D digital model through standard meshing and optimizing procedures; ii) a photogrammetric survey exclusively focused on the investigated monument, consisting of 986 photos (Single Lens Reflex Camera Nikon D5200 equipped with Nikon AF-P 18-55mm f.3.5-5.6 DX VR lens) taken with X-rite Colorchecker target, to achieve colour-balanced texturing of the surfaces (fig. 5).
The acquired data were processed using a Reverse Modelling (RM) application, which represents the current state of the art in the field [2]. When properly employed, these tools align effectively with the goals of architectural design analysis. The adopted workflow protocol includes the conversion of the point cloud model into a high-resolution mesh, which serves as the analytical foundation for subsequent investigations. The resulting mesh features an average edge length of approximately 4 mm, enabling the efficient processing and interpretation of high-resolution mesh models derived from point cloud data as follows:

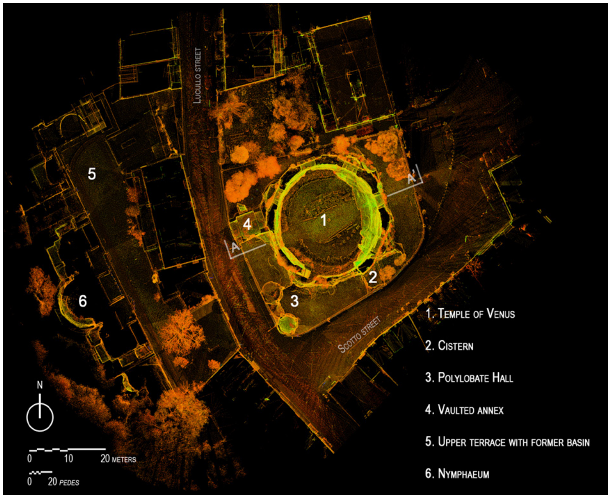
- interactive definition of planes, vectors, and reference points necessary for the creation of two-dimensional templates. These references are strategically positioned to identify original architectural elements and to distinguish them from later restorations or alterations resulting from human intervention or natural causes;
- geometric elements such as planes are employed in multiple analytical operations:
  - to extract sections that provide accurate documentation of the built structure;
  - to generate best-fitting 2D profiles, which serve as a basis for interpretative readings of the architectural design;
  - to derive contour lines that reveal traces of the original vaulted surfaces, particularly in areas where the intrados has suffered degradation, thus offering valuable clues for reconstructing the initial spatial configuration;
- from a carefully selected collection of points or regions –either manually defined by the operator or automatically extracted– it is possible to derive geometric primitives, such as solids or surfaces, that approximate the original vaulted system. These idealized forms serve as analytical proxies, enabling a more analytical interpretation of the remains;
- an additional functionality lies in the ability to compare idealized models and forms –based on NURBS surfaces or solids– with the corresponding original mesh, thereby enhancing the accuracy and reliability of the entire reconstruction and interpretation process.

In addition, for some of the more in-depth investigations, a dedicated process was developed, based on best-fitting algorithms for curves and quadric surfaces.
The data obtained through reverse modelling protocols are employed to test the hypothesis that ancient architects may have adopted a generalized approach to vaulted structures,

as outlined in certain surviving texts attributed to Hero of Alexandria, specifically *Stereometrica I*, *Stereometrica II*, and *De Mensuris*. Although Hero's original treatise on vaults '*ta kamarika*' [Conti, Martines 2010] appears to have been lost, recent research by Roca, Juan-Vidal, Cipriani, Fantini [Roca et al. 2023] suggests that portions of its content may have survived in editions by Heiberg [Heiberg 1914a; Heiberg 1914b]. Hero builds upon Archimedean studies, simplifying them with a technical and applied focus. When reduced to their essential mathematical expressions, the formulas and methods concerning the volume (constructive material) of arches, domes and vaulted spaces can be summarized as follows:

- subtraction of volumes (extrados minus intrados): the intrados of domes/arches is often based on a diameter of seven units or its multiples;
- use of 'average' surfaces –positioned midway between the intrados and extrados of a dome– which are then multiplied by a constant thickness to estimate the volume (here too, the diameter corresponds to seven units or a multiple thereof). A comparable method is also described by Hero in his approach to calculating the number of spectators in theatres [Bianchini, Fantini 2015];
- another method involves applying rectangular elements –such as cloths– onto complex surfaces, which are then flattened onto a plane for measurement. While this approach may offer a practical means of estimating areas of irregular shapes, it appears more appropriate for sculptures or freestanding elements than for the analysis of complex vaulted systems.

Fig. 3. Plan view of the TLS point cloud of the complex at the Archaeological Park of the Thermal Baths of Baiae, showing the main archaeological remains (point cloud registration and processing by S. Bertacchi).



One of the key aspects of the ancient architect's design method lay in reconciling a numerical dimension –what we might define as computational (*distributio*)– with a modular criterion permeating the entire building (*ordinatio*), and finally with graphic constructions of proven effectiveness and ease of execution using ruler and compass, such as the ad quadratum pattern or the dodecagon layout of the Latin theatre [3]. As a final observation, the value of π is consistently approximated as 22/7. For this reason, diameters are often set as multiples of seven, in order to simplify the calculation of the perimeter first, and subsequently of all related quantities, including surface areas and volumes.

Plan analysis

Regarding the interpretation of the plan design (*ichnographia*), the rotunda appears to be generated by its inner circle, which follows the same design logic as other buildings from Hadrian's time, namely the use of a diameter multiple of the number seven. This can be observed in well-known buildings at Hadrian's Villa, particularly in two domes that are still in a good state of preservation within the so-called Golden Court complex. In the case of the Eastern Triclinium, the intrados of the hemispherical semi-dome displays a diameter corresponding to seven modules of 5.5 *pedes*. A second example, also within the same pavilion, is the vestibule that provides access to the large portico (fig. 6). Here, the recurrence of the number seven is less explicit: while the *triclinium* expresses it through the number of modules, the vestibule measures six modules of 5.5 *pedes* (33 *pedes*), to which an additional 2 *pedes* –corresponding to the distance between intrados and extrados– must be added, reaching a total of 35 *pedes*. A similar recurrence is found in the semi-dome of the *Serapeum*, where the plan reveals eight modules of 7 *pedes*, again suggesting a compositional logic based on multiples of seven (fig. 7).
Once the diameter of the inner structure (26.57 m at +9 m from the ground level) was obtained through reverse modelling tools, it was divided by the standard *pes*

(1 *pes* = 0.2956 m), yielding a measurement of approximately 90 *pedes* (89.88 *pedes*) for the best-fitting diameter (D_{BF}) (fig. 8A). Assuming this rounding, and considering π = 22/7, the following module (M) is derived:

$$M = 90/7 = 12.86 \textit{ pedes} \approx 13 \textit{ pedes} \quad (1)$$

It is not unexpected that the result does not return a whole number, likely due to the precautionary principle that the Roman engineer consistently employed when designing innovative structures, such as the great vaulted space of the Temple of Venus. In fact, the calculation to determine the design diameter (D_D), carried out at the initial dimensioning stage, could have been as follows (fig. 8B), where the design circle (in red) can be subdivided into seven modules of 13 *pedes* each:

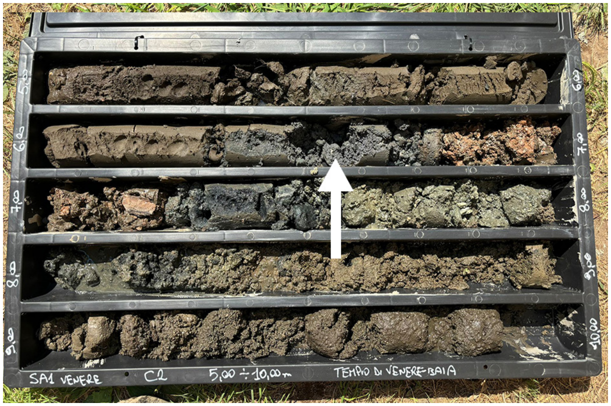
$$D_D = 7 \times 13 = 91 \textit{ pedes} \quad (2)$$

This value may have been reduced to 90 *pedes* to allow for greater wall thickness. Considering the masonry along the sides of the octagon, the thickness varies by a few centimetres; nevertheless, the value fits with the modular grid, namely half a module (*M/2* = 1.921 m = 6.5 *pedes*). The building's layout in plan is also based on the *ad quadratum* scheme, within which a circle of eight modules is inscribed: the drum is defined with a side length of S_{AQ} = 104 *pedes* (8 modules of 13 *pedes*) (fig. 8B). As previously observed by Rakob [1988], the width of the buttresses also relates to the modular grid of 13 *pedes* that guides the building's sizing. In fact, the flat sides of the external octagonal structure between the buttresses measure an average width of 26 *pedes*, while the windows measure 13 *pedes*, further confirming the modular logic (fig. 8C).
At the corners, the vertices of the octagon are reinforced by angular masses (amplitude ca. 17°), which increase the resistant thickness to about 10 *pedes* (fig. 8D). Their curvilinear silhouette further emphasizes the structural role of these reinforcements, compared to the 6.5 *pedes* of the walls consistent with the modular scheme.

Elevation analysis

Regarding the elevation design, the vault exhibits features closely comparable to other Hadrianic examples conceived on circular plan layouts, notably the *Serapeum* of Hadrian's Villa and the *Horti Sallustiani* in Rome [Eramo, Cinque 2024; Eramo, Fantini 2024]. In all these cases, the overall design conception is based on the definition of a governing form, usually recognizable in the shape of the simplest segments, generically referred to as 'coves', and subsequently elaborated through the addition of the *trikentron* and other smaller elements that regularize and soften the final built shape. In line with this design approach, the investigation of its geometrical conception was carried out through the analyses discussed below, with a focus on the overall configuration. The surviving structure, however –especially its intrados surface– is highly degraded and smoothed by erosion phenomena, making a reconstruction of its original shape an inevitably interpretative process, albeit grounded in objective and verifiable data (fig. 10).
Given the poor present state of conservation of the vault, a preliminary step of the analysis consisted of manually segmenting the polygonal model to isolate the best-preserved portions that still correspond to the original intrados surface.
Then, three complementary methods were used to analyse the model. The first consisted of identifying vertical sections of the coves, traced along radial planes significant in relation to the symmetry of the plan design (fig. 10A). The best-fitting circumferences ($C_{BF}V$) for these sections were then evaluated. The resulting circumferences

Fig. 4. Core samples from the current floor level at the center of the temple reveal the presence of an ancient pavement at approximately –6.6 m (samples by E. Gallocchio).



exhibited a marked variability in radius (ranging from 13.93 m to 15.52 m) and displacement of their centres from that of the drum (ranging from 0.6 m to 1.2 m). Nevertheless, they share relevant features: they are consistently very close to tangency with the impost best-fitting circle ($C_{BF}H$), which corresponds to the vertical rotation of the drum's horizontal section. Moreover, their radii are systematically larger than that of the impost circle (fig. 9B). Concurrently, the same portions of the model were subjected to a comprehensive analysis using a custom-developed shape recognition tool, based on a Matlab function for best-fitting generic quadric surfaces [Petrov 2015].

Fig. 5. A. Polygonal mesh model of the temple (digital elaboration by S. Bertacchi); B. Photogrammetric model with texture (digital elaboration by E. Eramo).

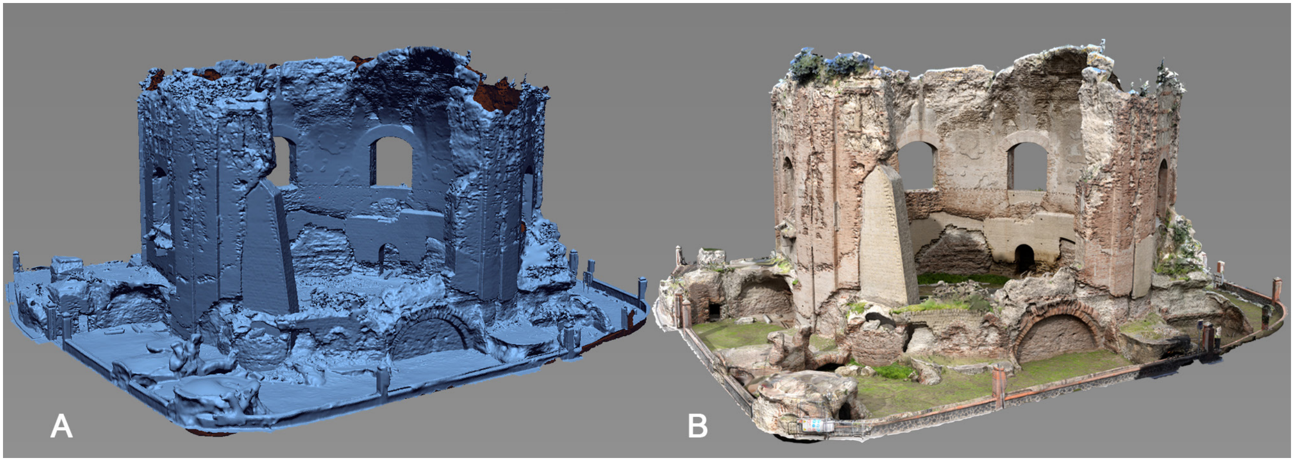
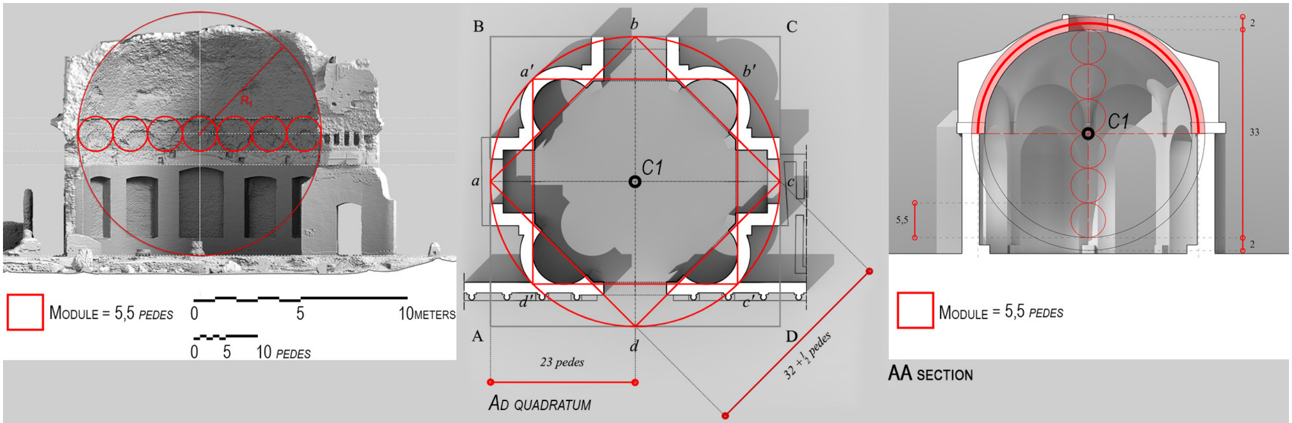
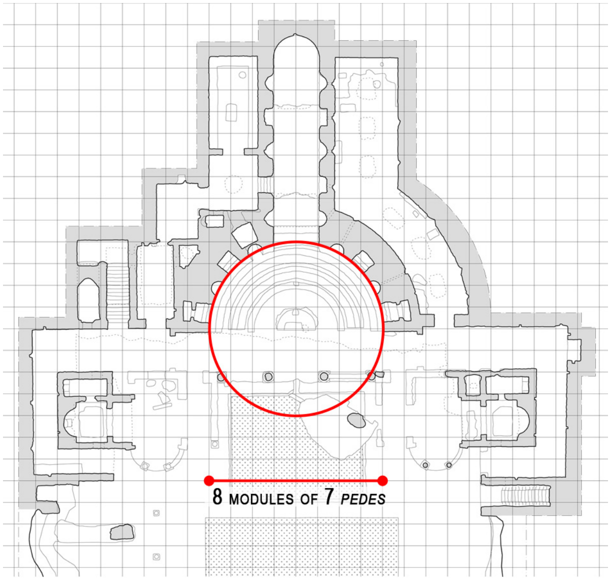


Fig. 6. East triclinium at the Golden Court, Hadrian's Villa: intrados of hemispherical dome with modularity of seven units (module = 5.5 pedes), (digital elaboration by F. Fantini).



The resulting surface is an ellipsoid (E_{BF}) whose principal radii, although rotated with respect to the symmetry axes of the complex, are still comparable to them. The rotation is attributable to the asymmetrical extension of the remaining portions of the coves between the west and east sides of the complex (see fig. 3). The quasi-horizontal radii, specifically, measure 13.31 m and 13.38 m, values very close to the radius of the dome impost circumference (13.28 m). In contrast, the approximately vertical radius is greater in size, measuring 13.69 m (fig. 9C).
The results of the first two analyses indicate that the overall geometry of the vault clearly deviates from a spherical form, such as in the case of the *Horti Sallustiani*. Moreover, the outcome of the quadric fitting must be interpreted differently from the case of the *Serapeum*, where the underlying geometry coincides precisely with an ellipsoid. In the case of the Temple of Venus, the best-fitting procedure did not yield a shape exactly matching the vault. Nevertheless, it is still useful as qualitative evidence that the overall development of the structure was more elongated in the vertical direction than a simple spherical surface.
Finally, the results of the previous analyses become clearer when examined considering the contour lines study. For the complete model of the vault, contour lines were extracted at 0.5 m intervals. As shown in fig. 9A, the horizontal sections display, in correspondence with the circular sectors of the coves, a linear rather than curvilinear pattern, with a decreasing slope in the radial direction. In addition, within the sectors corresponding to the window openings at the impost, distinct curved and steeper portions of the *trikentron* can be identified. Lastly, narrow areas can be observed between the two groups of segments, where the contour lines follow straight paths with varying horizontal inclinations. These areas, which narrow towards the summit, clearly denote a connecting function between the two main groups.
These findings confirm, in accordance with Rakob's proposal [Rakob 1988], that the covering of the Temple of Venus was conceived as a large umbrella vault. The dome was in fact formed by eight cylindrical segments with an increased radius compared to the impost drum, bearing down on the corner reinforcements. The segments above the windows, shaped by the double-curved surfaces of the eight *trikentron*, were connected to the former through transitional surfaces that softened the intersection edges. These findings highlight the refinement of the design strategy. In contrast to the above-mentioned comparative cases, where a circular plan corresponds to a geometry defined by a convex double-curved surface, the roofing of the Temple of Venus was conceived through geometrically simpler segments. Owing to the large impost diameter, these segments can approximate the curvature of the drum with sufficient accuracy. They are connected through local adjustments to the drum and alternated with the *trikentron*, whose original design remains to be clarified. Between the two groups of segments, transitional surfaces –generated from straight elements following the boundary curves of the adjacent portions– resolved the intersections and softened the intrados, producing a continuous and sinuous surface.
Finally, the results of the analyses were compared with the modular scheme identified for the plan, with the primary aim of verifying whether it also finds correspondence in the elevation design, thereby allowing the data to be interpreted within a unified and coherent framework of the

Fig. 7. Plan of the Serapeum-Canopus complex. The intrados measures 56 pedes, confirming modular logic based on multiples of seven (graphic elaboration by F. Fantini).



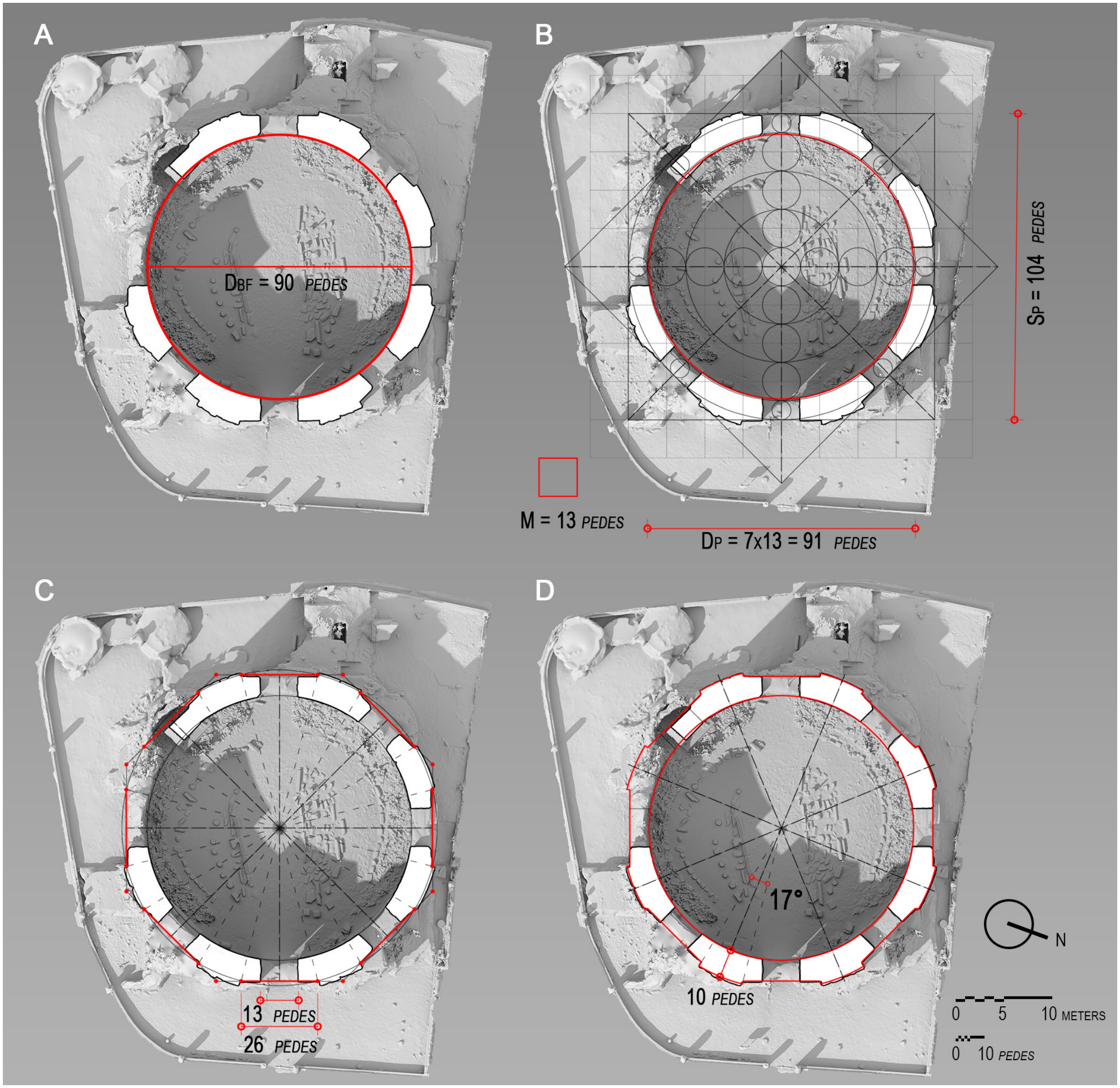


Fig. 8. Geometric analysis of the plan. A. DBF circle, ca. 90 pedes; B. Design circle equal to a diameter of 91 pedes with ad quadratum scheme; C. Dimensional layout of the external sides of the octagonal rotunda; D. Angular reinforcements at the corners (geometric analysis by F. Fantini, S. Bertacchi).

overall geometric project. To this end, the evidence provided by the core samples (fig. 4) was considered: these indicated a possible level of the original floor at approximately -6.6 m, as shown in fig. 10, consistent with that of nearby submerged structures.
Based on the evidence that the width of the windows in the drum corresponds to one module *M* (13 *pedes*), it was observed that the height of their jambs also coincides with the same measure. Moreover, the centre of the circle inscribed in the window coincides with the springing level of the cylindrical segments of the vault and was therefore assumed as the compositional centre of the elevation (fig. 11A). This choice provided preliminary positive evidence: the presumed ancient floor would in fact be located about -4.5 *M* from the identified centre, while the external façades, from the floor up to the level where the extrados of the dome begins to spring, would reach a height of 7 *M*.
Concerning the maximum height of the intrados of the vault, for which no direct evidence is available, the quantitative analyses suggest a greater vertical elongation, which does not appear to be consistent with the 8×8 *M* modular grid adopted for the plan design. A possible interpretation of the relationship between this elongation and the modular scheme was developed by hypothesizing a modular construction of the guiding arches of the cylindrical segments of the vault. A circumference of ½ *M* in diameter –the same measure that defines the wall thickness of the drum– was used to identify, along a radial direction, two eccentric points (C_1, C_2 in fig. 11A). Using these points as centres, arcs tangent to the drum on the side opposite the grid centre were traced, in accordance with the characteristics already identified in the best-fitting circumferences of the coves.
The comparison with the best-fitting ellipsoid E_{BF} shows that this construction yields a maximum height consistent with the results of the analyses, while further quantitative evidence reinforces its coherence: the arches in fact present a radius of 3¾ *M* and a displacement of ¼ *M* from the centre (i.e., about 14.40 m and 0.95 m), values approximately intermediate between those determined

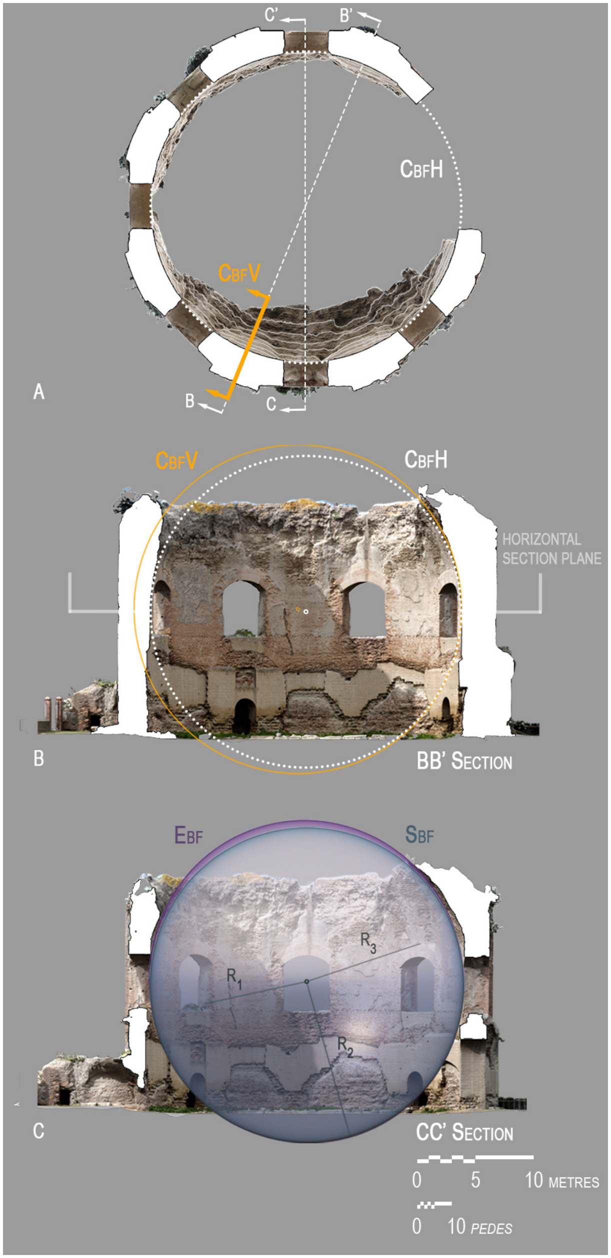


Fig. 9. A. Hypographic view with contour lines and impost best-fitting circumference (CBFH). B. Best-fitting circumference (CBFV) for the median section of the NE cove. C. Best-fitting ellipsoid (EBF) and best-fitting sphere (SBF) for the intrados of the coves (geometric analysis by E. Eramo).

through quantitative analysis. In the case of the best-preserved cylindrical segment, on the NE side, this generating arc offers a reliable approximation of the best-fitting circumference of its section (fig. 11B).

Conclusions

The monument as a whole recalls recurring themes found in other examples; notably, the alternation of coves and *trikentron*

Fig. 10. Section AA' (see fig. 3) showing the relationship between the upper terrace, the Temple of Venus, and the level of the ancient pavement (–6.6 m), (digital elaboration by S. Bertacchi).

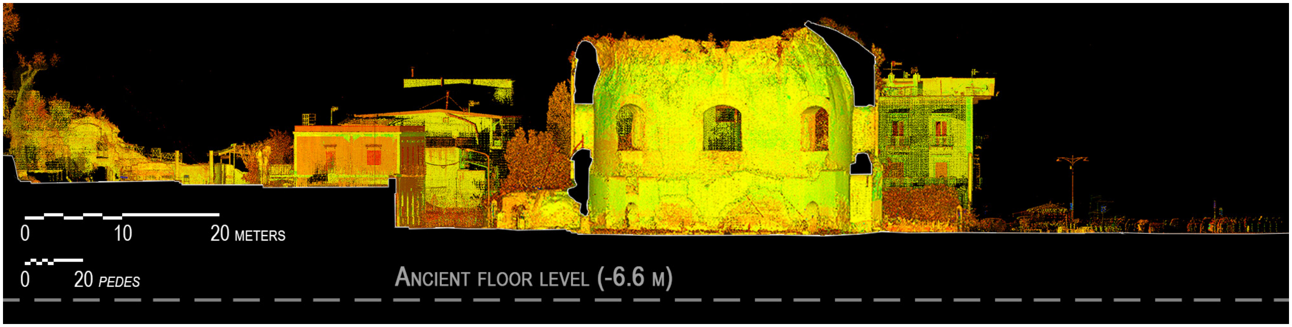
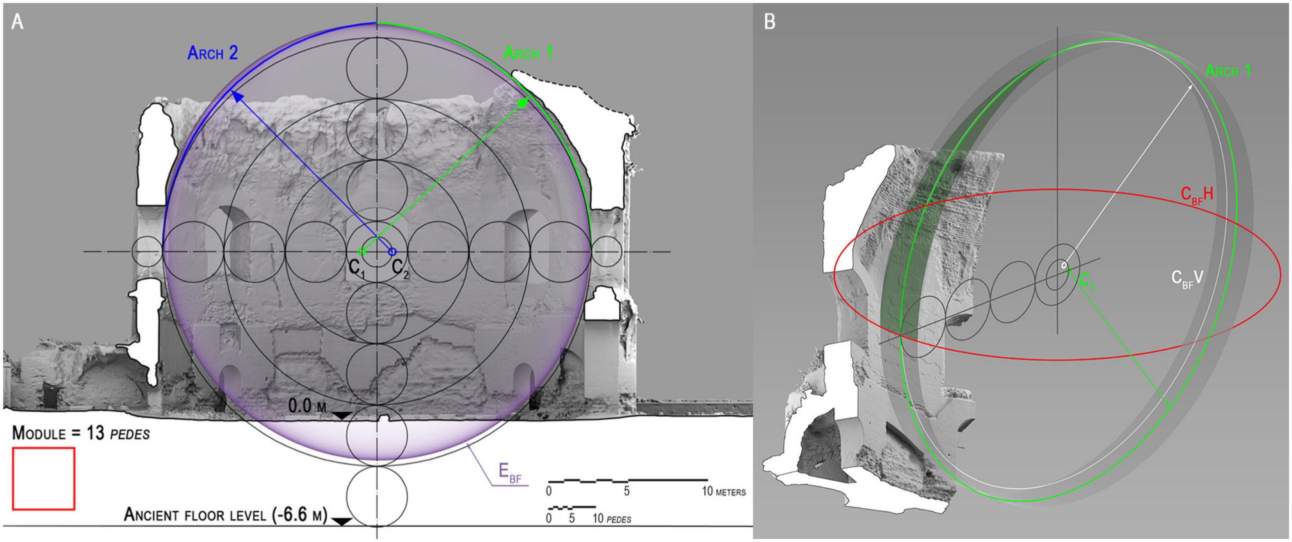


Fig. 11. Geometric analysis of elevation. A. Section AA' with modular grid, hypothesized tracing method of the cylindrical segments (blue and green), and best-fitting ellipsoid. B. Axonometric view of the NE cove with the design arch (green) compared to the best-fitting circumference (geometric analysis by E. Eramo).



draws parallels between this dome (diameter 26.57 m) and the previously mentioned domes of the *Horti Sallustiani*, albeit smaller (diameter 11.20 m), and that of the *Serapeum* (diameter 16.55 m), which lacks polar symmetry since it is projected towards the front of the building [Eramo, Fantini 2024].
Two noteworthy parallels can be observed in the planimetric design of the main rotunda of the Temple of Venus and the octagonal hall of the Small Baths at Hadrian's Villa. The first concerns the use of a diameter corresponding to seven modules for the sizing of these interior spaces (with a module of 5 *pedes* at the Small Baths and 13 *pedes* at the Baian building); the second relates to the wall thickness, which in both cases equals half a module. In both buildings, the use of the *ad quadratum* scheme is evident and appears to be a recurring feature that links domed spaces in Hadrianic architecture [Fletcher 2019], whether based on octagonal or circular plans, despite clear typological and constructional differences between the two forms [De Angelis d'Ossat 1936].
These geometric schemes may be regarded as general-purpose tools –scalable and flexible– designed to facilitate calculations, particularly those involving circular areas. Diameters that are multiples of seven simplify the computation of circular surfaces, while the *ad quadratum* scheme allows for straightforward doubling of such areas. Comparable considerations, although based on different *ichnographia* patterns, underpin the generation of both Latin and Greek theatre plans (*De Architectura*, V, 5 and 7), and, as demonstrated by Lara Ortega [Lara Ortega 1992], they can be adapted to both new constructions and the modification of existing buildings. Beyond this approach, based on philological analysis applied to surveyed buildings, recent archaeological evidence has also provided significant insights into the history of architectural design, as in the case of the slab bearing the carved plan of Galerius' Octagon at Thessaloniki [Savvides 2021]: this 'drawing' clearly demonstrates the use of the *ad quadratum* scheme and was found near the well-known building constructed towards the end of the third century AD. It also demonstrates the reception and continued use of graphic tools analogous to those employed in Hadrianic architecture, even in later historical phases.
The results obtained open the way for further research perspectives. In particular, the small mixtilinear extension of the Temple of Venus should be investigated in greater depth, since it represents another interesting example of experimentation in the context of other Hadrianic buildings, i.e., the Small Baths, the Mixtilinear Atrium [Ottati 2022] and the southern hall of Golden Court [Adembri et al. 2014] at Hadrian's Villa. Moreover, the complex at Baiae was not limited to the building of the Temple of Venus but extended to the slope behind it [De Angelis d'Ossat 1977], where there was a series of descending terraces, and to the area facing the sea. Future research should extend the analysis of the modular grid underlying the entire complex to investigate its design within a unified compositional framework.

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Notes

[1] The term *trikentron*, as used by Hero of Alexandria (*Stereometrica I*, 96), refers to a surface portion defined by three arcs of circles whose centres lie on different planes [Roca et al. 2023].

[2] The RM software used is 3D System Geomagic Design X.

[3] A crucial aspect in the planimetric design of the Latin theatre –and, by extension, of other buildings with a circular ground plan– consists in identifying a principal circle (*perimetros imi*), whose diameter must be divided into modules. From this foundational geometry, the well-known Vitruvian construction is developed [Salvatore 2007].

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The External Structure. For an Aesthetic of Facade

Paola Raffa

Abstract

In the urban landscape that had seen a strong adherence to languages based on neoclassical eclecticism, as a requirement for civic decorum, during the pre-war reconstruction phase, Messin''s residential architecture, between the 1950s and 1960s, participated in the national and international debate, assimilating the linguistic codes of the Modern Movement and the International Style.
The new multi-story collective buildings, located in vacant blocks or completing undeveloped areas, brought references to a modern home in both their language and their amenities. The aspiration toward international modernity also became a social connotation. It was primarily engineers, designers, and builders who undertook syntactic reinterpretations in which the language of the façade developed new and bold solutions, in line with technical experimentation. The openness to new modern and rationalist tendencies nevertheless allowed for the ability to unify the architectural composition starting from structural data.
The facades are arranged within the urban block, sometimes as separate parts, in terms of height, colour, and materials, other times perfectly inserted into the regularity and scale of the rigid urban grid.

Keywords: architectural representation, project graphics, archive drawings, graphic languages, architectural analysis.

Introduction

The architectural works between the 1950s and 1960s in Messina [1] brings together a lot of examples whose main reference lies in the collective residential buildings of the Cortina del Porto, designed and built between 1952 and 1958 by Giuseppe Samonà, in the INCIS housing, built between 1949 and 1952 and designed by Mario Ridolfi, and in the experimental and innovative architectural styles by Roberto Calandra, Filippo Rovigo, and Vincenzo Pantano, who actively participated in the contemporary national and international architectural debate [2].
The facades of Cortina del Porto designed by Samonà (fig. 1), which stretch for a kilometer along the seafront, assert as a physical and theoretical manifesto, visible in its materiality, in which the assumptions of architectural composition are expressed, finding their greatest references in the fusion between the legacy of the Modern Movement and that of the International Style (fig. 2).
Engineers and architects, mainly coming from the Schools of Palermo and Rome or from the Academies of Fine Arts [3], undertake stylistic reinterpretations in which the language of the facade declines new and daring solutions, which fit into the regular framework of the *Piano Regolatore* by Luigi Borzì, designed for the reconstruction after the 1908 earthquake. The anti-seismic laws issued specifically for the Strait of Messina, the use of new construction technologies, the experimental use of reinforced concrete, give the city the dimension of an innovative laboratory both on the architectural and urban scale.

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In those years, the horizontal city skyline, with low-rise buildings and wide streets, envisioned by the Borzì Plan and stringent building regulations, was redefined. The new multi-level, collective buildings, located in empty blocks or completing undeveloped areas, brought the hallmarks of a modern home in terms of both language and amenities [Caramellino et al. 2015] and the aspiration toward international modernity.

Collective and middle-class housing

Coinciding with the years of the 'economic miracle' between the early 1950s and the 1970s, we are witnessing a strong growth of the city center. Messina, destroyed by the earthquake and bombings of World War II, is affected by a massive repopulation by families from the province and the wider region. A nascent middle class emerged, which, in line with national trends, demanded new living comforts combined with growing economic prosperity. In this context, uncontrolled demand for new housing increased. The Italian economic 'boom houses', predominantly multi-level collective housing, were intended for the middle class, who, given rising incomes, were able to aspire to a "medium-to-large condominium apartment, with modern and comfortable layouts and distinctive architectural elements that confer the character of luxury housing" [Zanfi 2014, p. 3].

The apartment house comprises a typology capable of containing some symbolic elements of modern living space, which is embodied in the "play of representations through which the building can be perceived as suitable for a certain type of inhabitants" [De Pieri et al. 2014, p. XIX] [4]. The living space, in line with new social behaviors, tends to open up more and more towards the outside "and to act as a sort of showcase for the building" [De Pieri et al. 2014, p. XX]. The house open towards the outside, and the request for large spaces onto which to project the internal living, favors the articulation of the facade in the relationship between the compositional elements that determine the architectural language.

Balconies and windows become much larger than the small, but necessary, vertical elements, and are combined with extremely protruding structural artifacts, the result of previously unheard-of structural experimentation.

This results in a modification of the urban landscape, which, in the architectural production of the interwar reconstruction, had seen a strong adherence to languages related to neoclassical eclecticism as a necessity for civic decorum. The city was emerging from a period of neoclassical revival, in which modern building materials were used to reproduce decorations and stylistic elements that harked back to the classical language of the Academies. This marked a clear disconnection from the search for lost aesthetic simulations.

Fig. 1. G. Samonà, Cortina del Porto, 1952-1958. Blocks IV, V, VI (photos by the author).

The engineers' approach, instead, was to enable the new materials in technical-constructive performances linked to a linguistic-formal expressiveness, in an unconscious accord with Heideggerian unveiling.
Even before the work is completed, intense graphic design work is required. Mario Manganaro, speaking of Messina, writes that "the paper city represents the city of possible ideas […] without which the real city is less comprehensible, appearing like a reduced city […] the existing city, from a material point of view, is only the visible part of what has managed to materialize of the possible city" [Manganaro 2011, p. 8], underlining the difficult condition of Messina's archives.
Building construction in those years was a highly bureaucratic process; the request for a building permit was preceded by the extensive production of documents that guaranteed the conformity of the construction (fig. 3).
The archival files reveal a graphic production that highlights an original experimentation with the metalinguistic codes of drawing, the main reference for which is Mario Ridolfi's *Manuale dell'architetto* from 1946. This constitutes an excellent reference for designers, not only for the codification of representation but also as a tool for functional, technical, constructive, and formal solutions [Unali 2003; Unali 2008].
The archival documents highlight a series of professional figures [5] who are dedicated to the production of administrative documents, from building permit requests to a continuous succession of variants, testing certificates, correspondence between offices, etc.
Messina's engineers only, at least during the initial phase, in association with construction companies, played a central role in the city's aesthetic construction process. Messina "entrusts engineers, or rather, individual engineers, almost entirely, with responsibility for the entire design process: from the architectural to the structural, from the systems engineering to the construction site planning" [Cardullo 2009, p. 84].

The facades of engineers (and a few architects)

In the panorama of national building production, cultured, intellectual professionals did not disdain structural research and experimentation with materials [Capitanucci 2021]. The avant-garde trends promoted by the magazine *Casabella* directed by Ernesto Nathan Rogers, by Giò Ponti's magazine *Domus*, by *Stile*, l'*Edilizia Moderna*, L'*Architettura* are of great reference, as well as a fruitful editorial production on the state of new quality architecture, built in large Italian cities, one above all the *Antologia di Edifici Moderni in Milano* compiled by Pietro Bottoni in 1954. Bruno Zevi, director of *L'Architettura. Cronache e storia*, assign to Roberto Calandra the direction of *L'Architettura in Sicilia*, a supplement to the magazine published in 1956 and 1957.

Fig. 2. F. Rovigo, block 156 (1956) and block 131 (1955); V. Pantano, block 157 (1952); M. Ridolfi, Case INCIS, 1949-1952 (photos by the author).

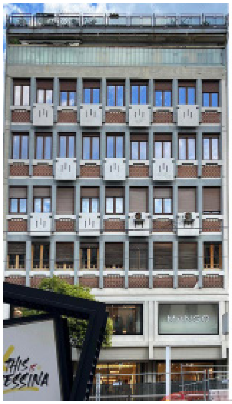
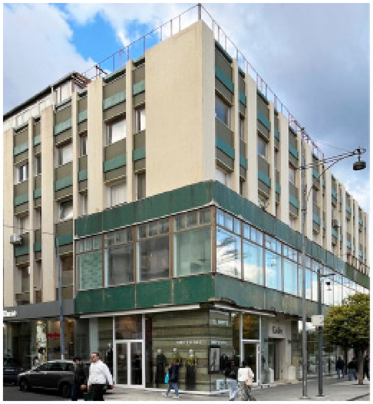
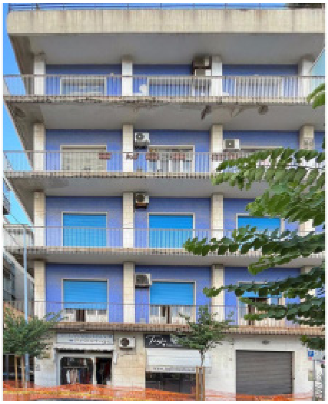
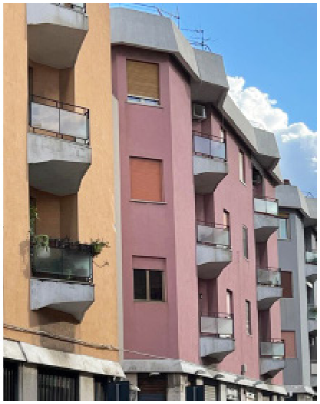
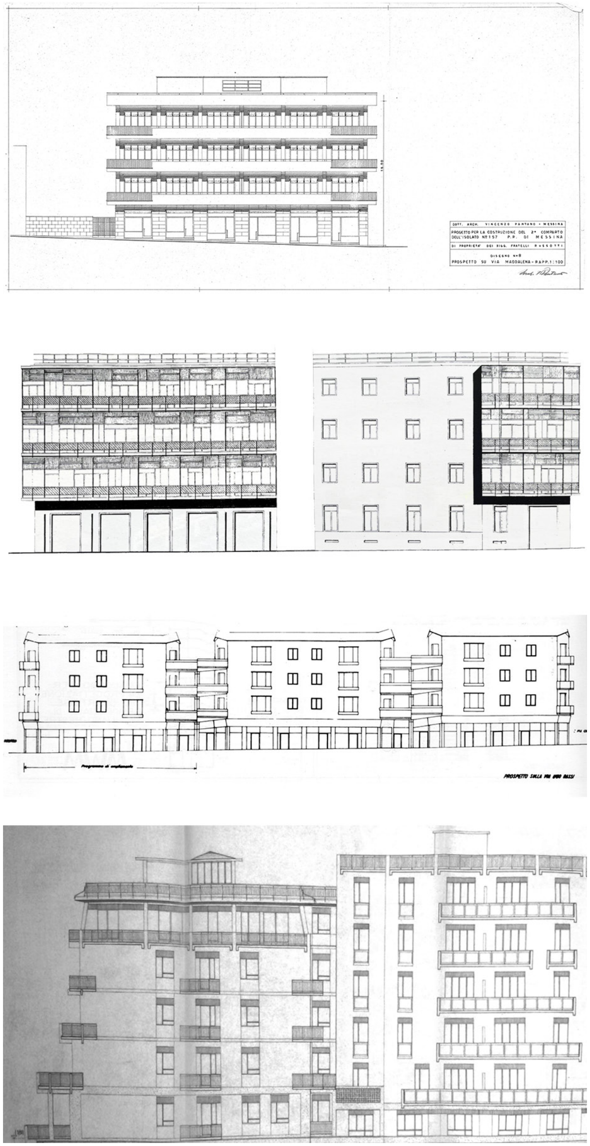





Fig. 3. Archival drawings, (from top): V. Pantano, elevation of block 157 (1952); F. Rovigo, Casa Donato, is. 270 (1953); M. Rifdolfi, Case INCIS, is. 276 (1949-1952); R. Calandra, G. De Cola, A. D'Amore, is. 481 (1955); (Messina Civil Engineering Archives).



The theme of multi-level collective housing became a field of experimentation and discussion, starting with subsidized housing and the INA Casa plan, the first examples that focused on the architectural debate of Italian Rationalism. Attention was always focused on structure, the industrialization of materials, and compositional expressions closely linked to the artistic avant-garde, a source of collaborations between designers and artists.
Some professional studio engaged in the reconstruction of Messina were driven by intellectual impulses that inspired original semantic elaborations, with a focus on broader national and international contexts. The delirium of construction, however, dictated the proliferation of repetitive and simulative linguistic patterns.
The 1950s were a period of transition from a style still tied to classicist forms to a language open to new modern and rationalist tendencies [Lingeri, Spinelli 1995, p. 46]. However, the ability to maintain the unity of the work through style, starting from structural data, existed. The theme of the block, or part of its, was treated unifiedly, both from a morphological-typological and urban perspective. This approach clearly harks back to the stereotypes of rationalism and the Modern Movement.
Beyond of ideology, to which the small group of the architects' guild resorted, and leaving aside the theoretical foundations of rationalist and modernist architecture, some engineers devoted themselves to solving problems related to the home: size, layout of services, reception areas, and the construction of a language derived from structural behavior, which in the most interesting examples does not overlook the unified layout of the entire facade.
The clear sequence of the basement, with commercial areas, the intermediate floors of the residences framed by cornices marked by plaster, mosaics, or stone slabs, with the definition of mirrored or axial symmetries, created by the vertical alignment of openings, by continuous solid elements, or simply by the transparency of metal parapets, the crowning of the top floor with its airy suspended solutions defines the architecture in complete configurations (fig. 4).
The prevalent pattern found in Messina's facades accentuates the primary structure of the reinforced concrete span, from pillar to pillar, maintaining the repetition of the load-bearing element, with intermediate cadences of secondary structures inserted into rhythmic serial scansions.

In some cases, pronounced narrow balconies jut out in a line or alternately, sometimes interspersed with aligned windows. Colored plaster or glass paste tesserae emphasize the verticality of the load-bearing structure without intermediate interruptions.
When the facade is flat, no element assumes hierarchical dominance. The rigid score allows for no exceptions: measure and rhythm are repeated. This results in simple geometric regions, the square and the rectangle, which can be broken down into complementary figurative elements (fig. 5).
In the case of a dense network of protruding vertical elements, the facade, according with the daylight, participates in the rhythm of time.
The engineers' frame structure, superimposed on the building's box-shaped, consolidates new intermediate spatialities, generated by lines and surfaces detached from the facade plane. The ordering grid, as a forepart expressing the geometric framework, is an abstract support independent of the placement of the openings. It depends entirely on the load-bearing structure, marking its position with the doubling of the columns. A translated filigree in which the external space materializes as a volume in a relationship established by the correlation of the elements: continuous balconies with concrete parapets, a closing wall, and pillars. Highlighting the top with increasingly dense pillars or with protruding canopies consolidates the facade with classical references (fig. 6).
When the solution includes terraces, the structure is pronounced with partitions that extend along the entire length of the overhang; the need to break the monotony requires a misalignment or interruption of the non-structural parts.
The corner always presents specific solutions, accentuating a structural hierarchy, by highlighting the corner pillar, or compositionally, in which exceptional elements appear at intersections, attics, or overhanging balconies. It is the point where all the compositional tensions of the facade converge (fig. 7).
The elevated balconies enhance the large windows that project outward, addressing the theme of external domestic space in modern living practices, the relationship with urban space, and the panorama. The blocks, in adopting the negation of the courtyard type, draw directly from the Milan proposals of Terragni and Lingeri, in which the unitary synthesis of a single body is resolved with alternating volumes and aerial connections of balconies and canopies (fig. 8).

Fig. 4. V. Cacopardo, block 106 (1953); Viale della Libertà, block 515; (photos by the author).

Fig. 5. Buildings with facades defined by coplanar structural elements (photos by the author).

The colors of the plaster, the glass paste tesserae, or the ceramic tiled panels emphasize the reference to the figurative arts of the avant-garde, whose sentiments still resonate. Defining architecture through color is a choice that stems from a long meditation that harks back to studies of architectural chromatics, "an essential part of the creative process of a work that, precisely through these elements, establishes a strong relationship with the city" [Lingeri, Spinelli 1995, p. 105].
Bands running horizontally or longitudinally, panels inserted into defined squares between the openings, colored parapets that stand out from iron railings, bright, strong colors, predominantly blue and yellow, with green used to contrast the white reference planes, compose formal orders and clear references to De Stijl (fig. 9).

Ordered readings

The reading of the as a multilayered text is based on the "close relationship between theoretical orientation and operational practice" [Lingeri, Spinelli 1995, p. 41], which aims to achieve a unified architectural composition.
The facades clearly emphasize the predominantly vertical line of some primary structural elements, which present compositional rules punctuated by serial rhythms, and secondary lines when the overhang of the balconies exceeds the permitted dimensional limits and requires technical expedients to attenuate the loads. Structure becomes the language of architecture and defines its aesthetic canons [Raffa 2021].
The structural module, which identifies the elementary component of the composition, defines its geometry, formal composition, balance, and even construction technique.
A statically defined whole in the geometric-structural system that, on the facade plane, overturns the formal structure of the entire building, the compositional rules, and the logical-structural aggregation "indeed, it can be said that the formal-constructive characteristic of the architectural work that sets it apart from other figurative-spatial artistic expressions is precisely contained in its subdivision into formally autonomous, statically defined parts, capable of repeating themselves identically […] which intervene in the definition of the final body of the work" [Ricci 2011, p. 15].
The highlighting of the structural lines of force is combined with a synthesis of identification of the building's plastic lines. Drawing organizes elements to reveal the ordering relationships and laws that connect the parts. It presupposes a

Fig. 6. Via Ghibellina, block 160, frame system external to the building block (photo by the author).

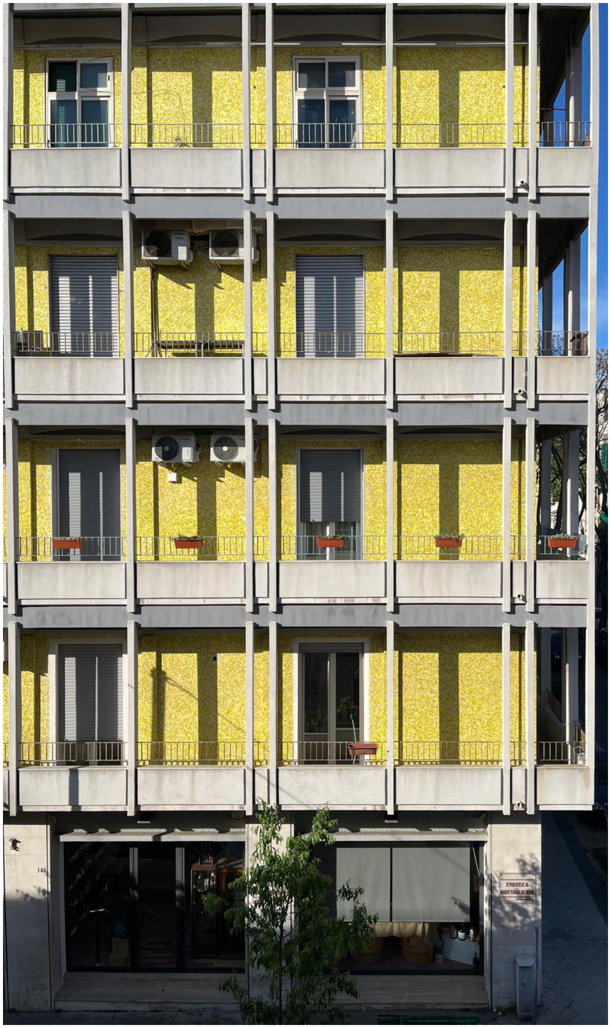


Fig. 7. Buildings with facades defined by structural elements external to the facade (photos by the author).

choice, an interpretation, which lies in the description, the placement of the sequence, and therefore the highlighting of the parts.
The grammatical and syntactic organization of compositional elements initiates the cognitive process, not only in terms of defining the elements and physical forms of the completed architecture, but also, through the rules of technical drawing, provides notions that introduce understanding of the design process.
The research for formalization in architecture has favored the simplification of representational codes in the encounter between structure and form. The definition of the representation is provided by the elementary geometric composition of the elements and the minimal consistency of the materials that must be translated into a sign.
The characteristics of seriality, combined with the simplification of technical processes, have legitimized an economy of sign that, however, does not correspond to the impoverishment of architectural configuration.
The comparison of congruent elements leads to knowledge and syntactic understanding of formal language, typology, and constructive logic: "from the comparison of notions derived from architectural observation, for example, we deduce those architectural elements characterized by greater formal stability: comparison, in other words, constitutes the very basis on which architectural classifications are built" [Grassi 1967, p. 39].

The frame, which is externalized in the reticular structure, for example, allows for the possibility of highlighting the generative matrix of the design principle. The breakdown into planes and the distinction between parts, which make the functional nature explicit, leads to the identification of the model in which repetitiveness and modularity are placed, among other things, as fragments of the aesthetic expression of standardization and industrial production. The exploration of the module, in the frame system, allows for the definition of syntactic relationships between the elements, characterized by their own form and different materials. Furthermore, the discontinuous frame system connects the exterior with the interior, both physically and through visual perception.

Conclusion

The issue of shared housing, condominium, is being addressed through its typology, new comforts, the social use of space, and the language of the facade. Experimentation with new speculative construction systems and the technical efficiency associated with the materials of the new mass industrialization are becoming the field of formal research for modern living. The new demands of the emerging bourgeoisie are aiming to advance demands not only for the interior of the home but also for its exterior design as a defining element of social status.

Fig. 8. Corner solutions of some blocks located in the city center (photos by the author).

Compositionally, Messina's blocks are the result of the area to be built, either the entire block or a section, generally a regular shape considered a single volume. Their design and construction are subject to rules building, and especially earthquake-proof mechanisms; they arise from rational actions based on functional, technical, and economic criteria, which have strongly influenced the design process [De Pasquale, Pino 1996].
The engineers' buildings appear not to be characterized by intellectual pulsations or linguistic research based on theoretical assumptions, but rather by emulations of local references, structural declinations, and the repetition of consolidated stylistic features.
Themes such as lightness and solidity emerge, however, never absolute but rather mutually balanced [Arena 2002]. The compact volume is overlaid with terraces, balconies, screens, or simply revetments; large balconies supported by slender concrete screens or metal profiles protect the interiors from excessive midday light. The facades are arranged within the urban block, sometimes as separate elements, in terms of height, color, and materials, other times perfectly integrated into the regularity and scale of the rigid urban grid.

Fig. 9. Facades with insertions of elements referencing avant-garde figurative arts (photos by the author).

Fig. 10. Elevations of the blocks (from left, from botton): block 362, block 154, block 476, block 13, block 244, block 376 (graphic elaboration by the author).

Notes

[1] Francesco Cardullo, professor of Architectural Design at Mediterranean University of Reggio Calabria, and Vincenzo Melluso, professor of Architectural Design at University of Palermo, are the main scholars of research on the architecture and urban structure of Messina after the reconstruction 1908 post-earthquake, which refers to the figurative and compositional characteristics of Modern Architecture. See in particular: Cardullo 1993; AA.VV. 1986.

[2] Roberto Calandra (1915-2015) and Filippo Rovigo (1916-1986), after graduating from the Scuola Superiore di Architettura in Rome, attended the School of Architecture at Columbia University in New York, where they encountered the masters of the Modern Movement. Upon returning to Italy, Roberto Calandra collaborated with, among others, Carlo Scarpa, and Rovigo with Giuseppe Vaccaro, Mario Ridolfi, and Giuseppe Samonà [Passalacqua 2021].

[3] In this regard, an exhaustive reconstruction is contained in the volume by Adriana Arena, *I disegni dei progetti per la ricostruzione di Messina* [Arena 2011] in which, in the first chapter entitled *Il percorso formativo per ingegneri e architetti tra Otto e Novecento in Italia con particolare riferimento alle discipline del disegno*, a detailed description of the teaching of drawing in the Italian panorama is provided and in the paragraph *L'insegnamento pubblico del disegno a Messina* (pp. 28-34) the case of Messina is described. In the *Presentazione* (pp. 6-9) the story by Prof. Mario Manganaro regarding the Drawing Institute activated at the Faculty of Mathematics of the University of Messina is very interesting.

[4] "A recognition that is the object of continuous negotiations between the actors and calls into question the symbolic and contractual aspects of the construction of social hierarchies" [De Pieri, Bonomo, Caramellino, Zanfi 2014, p. XIX].

[5] "In the 1950s, practically 100% of the projects presented and approved were signed by engineers. In the 1960s, 90% of the projects were the work of engineers and 10% were the work of architects. In the 1970s, 85/90% of the projects were by engineers and the remainder by architects […] More commonly, the specializations of non-civil and construction engineers who presented civil building projects in Messina after the 1950s were: hydraulic, industrial, electrical, transport, mechanical" [Cardullo 2009, p. 84].

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Forms of Resistance.
Structural Aesthetics and Imaginary

Invisible Cones of the Pantheon

Kristin Jones

This essay focuses on one of the great wonders of the built world –the Pantheon, constructed around 126 AD– and, through drawing, proposes a possible clue as to how its form may have been generated in relation to human perspective. The oculus is interpreted as a lens, connecting the individual viewer to the infinity beyond. Between the circular opening above and the finite point of the observer below, an invisible geometry is formed: the cone. This central cone is understood as the building's generative DNA, closely aligned with the internal workings of the human eye and the stereographic cones through which we perceive the world.
In attempting to understand how such an accurate building could have been conceived and drawn in antiquity, this essay revisits scholarly research into the generation of the dome's coffering and hypothesizes that principles of stereographic projection may have informed both the coffers' geometry and the precise diameter of the oculus.
This essay forms part of a broader artistic body of work, beginning with three-dimensional drawings that explore the Pantheon's invisible geometries, the phenomena of time and light, and its connection to the beyond. Ultimately, the work aims to inform an ephemeral installation that juxtaposes the monumentality of the Pantheon with the fragility of human life.

Introduction

The Pantheon, widely regarded as one of the most iconic monuments of the ancient world, remains enigmatic

This article was written upon invitation to frame the topic, not submitted to anonymous review, published under the editorial director's responsibility.

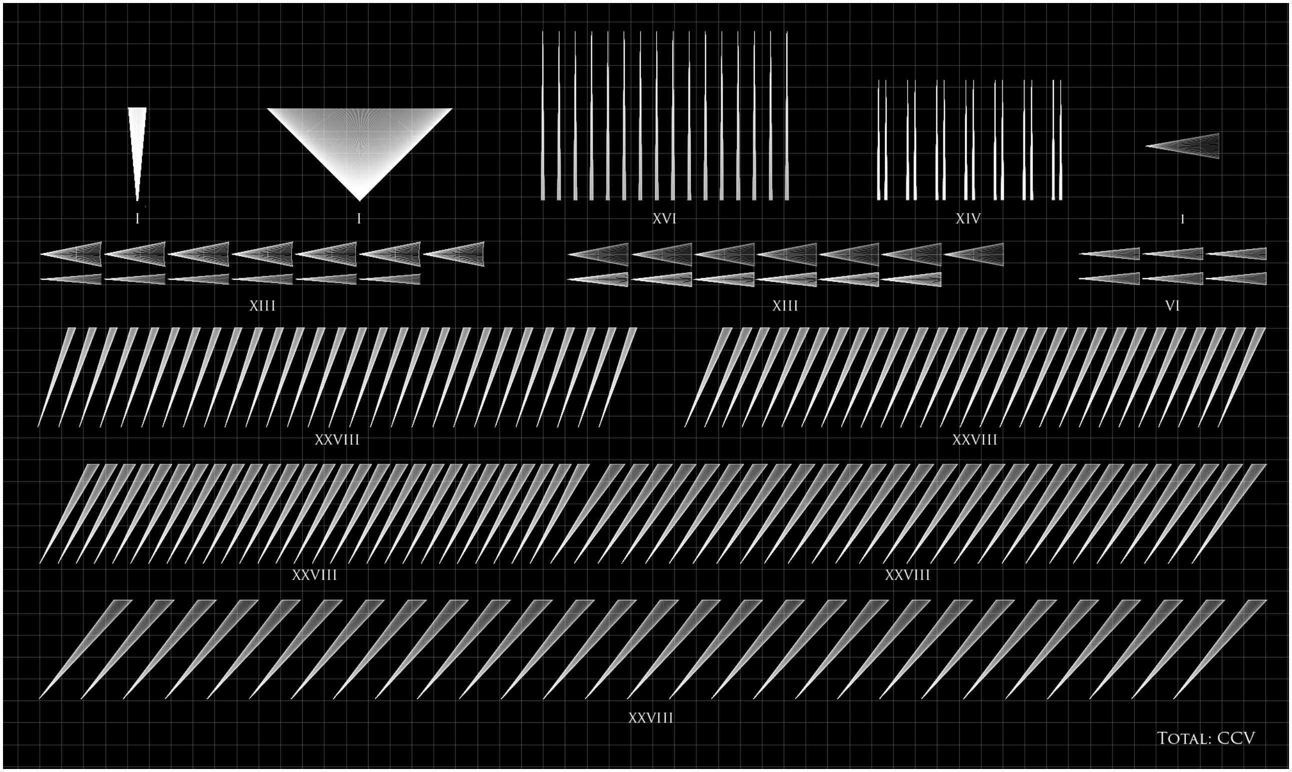


Fig. 1. The 205 invisible cones of the Pantheon (diagram by Brooklyn Richardson, 2025).

in many respects. Its unusual history, design, and construction continue to provoke scholarly debate. This artistic investigation addresses the relationship between the human eye and the building's geometry –beginning with the oculus (fig. 1). Central to the analysis is a hypothesis of architectural graduate Yuhao Jiang, made in collaboration with artist Kristin Jones for her project *Oculus: A Tribute to the Pantheon*, which suggests that stereographic projection may have informed the design and diameter of the oculus. Through a series of original illustrations by Jiang and others, the article visually examines the invisible presence of a cone embedded in the architecture and spatial logic of the Pantheon. It proposes that this conic geometry may offer an interpretive key to understanding the symbolic and optical intelligence of the structure.

Geometry and *symmetria*

Key to the construction of the Pantheon is the core concept of *symmetria*, or mathematical harmony, employed by Roman architects [Marder, Jones 2015]. This idea was a cornerstone of classical architecture and involved the use of simple arithmetical ratios and round number divisions in the planning of buildings. The interior of the Pantheon is well-known for being as high as it is wide, consistent with the notion of an inscribed sphere or a

hemisphere on a cylinder of the same height. Elemental geometry also governs the construction, with the orthogonal parts of the building conforming to the figure of a cube interlocking with the sphere of the rotunda interior (fig. 2).
The geometry involved in the Pantheon's design also gestures towards the symbolic importance of the structure. As early as the third century, the vast dome was interpreted as a symbol for the vault of the heavens. Greek author Cassius Dio offers this opinion in his work *Romaiká*, writing on the source of the building's name: "The Pantheon is called so, perhaps, because it contains the statues of many gods, including Mars and Venus; but my own opinion is that, because of its vaulted roof, it resembles the heavens" [Dio, 53.27.2].
Furthermore, describing the view presented by the building's interior, Giangiacomo Martines, architect with the Soprintendenza Archeologica of Rome (Archaeological Superintendency of Rome), writes of the fundamental union of dome and cylinder presented by the rotunda, thus: "The only source of light, the oculus, draws the visitor to the center of the space, where we can wonder at the monumental interplay of a hemispherical dome resting on a cylinder of the same height, a geometry confirmed by modern precision surveys" [Martines 2015, p. 100].
The use of this geometric relationship in the Pantheon's design was no doubt informed by Archimedes' key work on the subject, *On the Sphere and the Cylinder*, written c. 225 BC. Here Archimedes includes key findings that the ratio of the volume of a sphere to that of a cylinder of equal height is 2:3, and also that the surface area of a sphere is equal to the lateral surface area of a cylinder with a height equal to the sphere's diameter and a radius equal to that of the sphere.

The cone in the Pantheon

Once within the space of the Pantheon's rotunda, visitors raise their eyes to look through the oculus and into the sky beyond. This conic configuration of observer and oculus is illustrated in figure 3.
As humans, everything we see comes to us by way of the geometric form of the cone. Our stereographic field of view is quite literally understood to be conic in shape (fig. 4). While our current understanding of optics has little in common with that of the ancients, the concept of a cone of vision was recognized by writers of the Greco-Roman world, most notably by the mathematician Euclid and astronomer Claudius Ptolemy [Euclid 1945; Lindberg1976, pp. 15, 16].
This cone of vision gains further significance when examining the architectural geometry of the Pantheon, particularly in relation to the work of Amelia Sparavigna and Lidia Dastrù (fig. 5) and their 2018 pre-publication article *The Pantheon, Eye of Rome, and its Glimpse of the Sky*. Here, the scholars propose that "the architect who planned the temple had been inspired by the form of the human eye to create a building representative of the link between Rome and the heavens" [Sparavigna, Dastrù 2018, p. 1]. This interpretation suggests the oculus may be read as a symbolic eye –one through which the mortal viewer gazes upward with conic vision toward the divine expanse above. Within such a sacred space, the geometry becomes not only architectural but metaphysical.
As figure 5 illustrates, the almost nine-meter diameter of the oculus allows the viewer who stands in the direct center of the interior to see an angle of ten degrees wide. Given the placement and proportion of the oculus, the Pantheon functions as a zenith telescope, which allows visitors to observe a small section of sky directly above Rome by narrowing the expansive view of the heavens, allowing for a more focused and detailed observation of a limited portion of the sky. With this, using the astronomical simulation software Stellarium, Sparavigna and Dastrù were able to calculate which stars would have been visible to an ancient Roman looking up through the oculus at night [Sparavigna, Dastrù 2018, p. 4].
However, it is notable that when examining the Pantheon in a high-definition Lidar generated digital model, the angular slice of sky is slightly larger than ten degrees (fig. 6), because for the angle to be exactly ten degrees, the viewer's eyes would have to be at the apex of the cone –which lies on the floor.
Could this explain the presence of the curious bronze drain cover at the precise center of the floor that resembles an eye-mask (fig. 7)?
Corroborating the proposition regarding the role of the 'eye-mask' drain in the Pantheon's floor, research in visual neuroscience underscores the critical importance of the central 5 to 10 degrees of the human visual

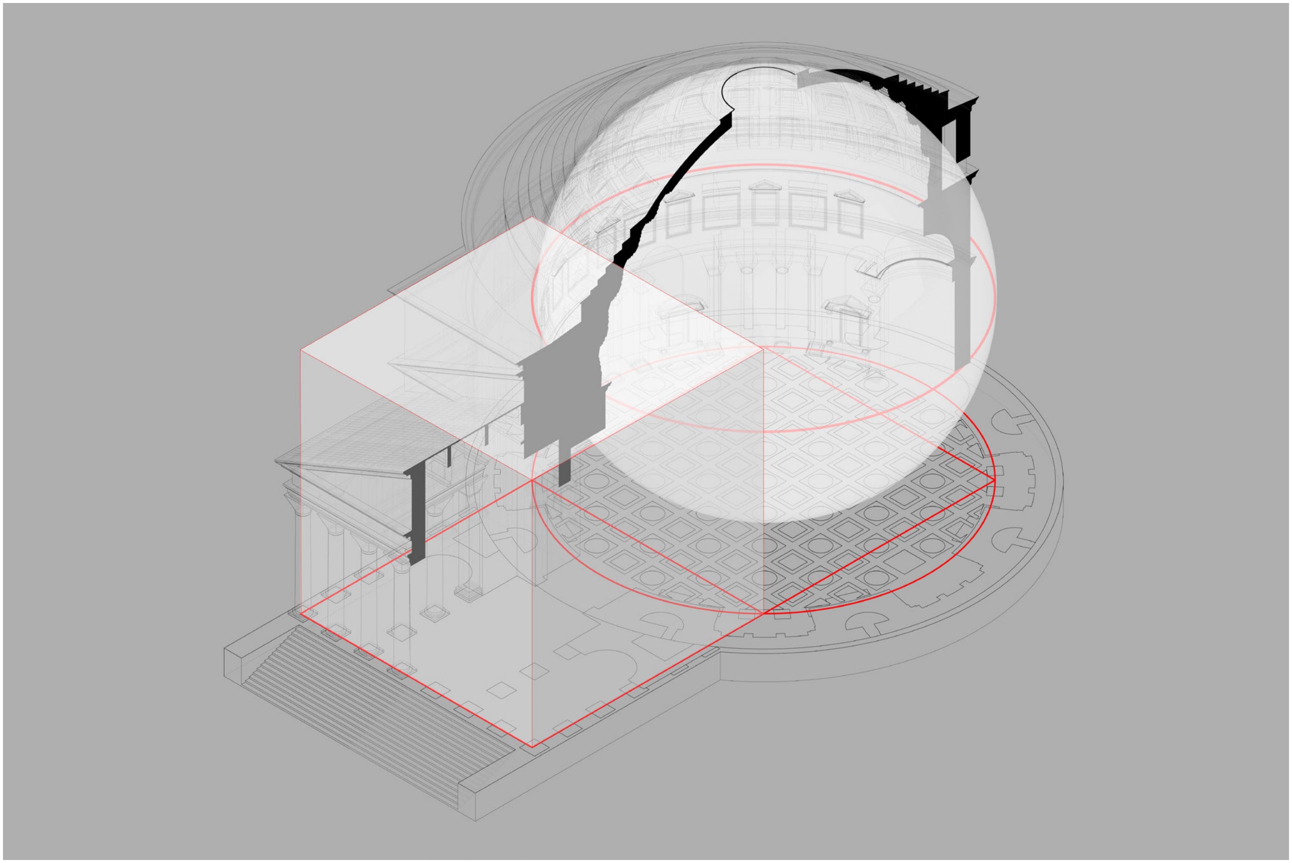


Fig. 2. Geometric Analysis, after Mark Wilson Jones, redrawn by Yuhao Jiang.

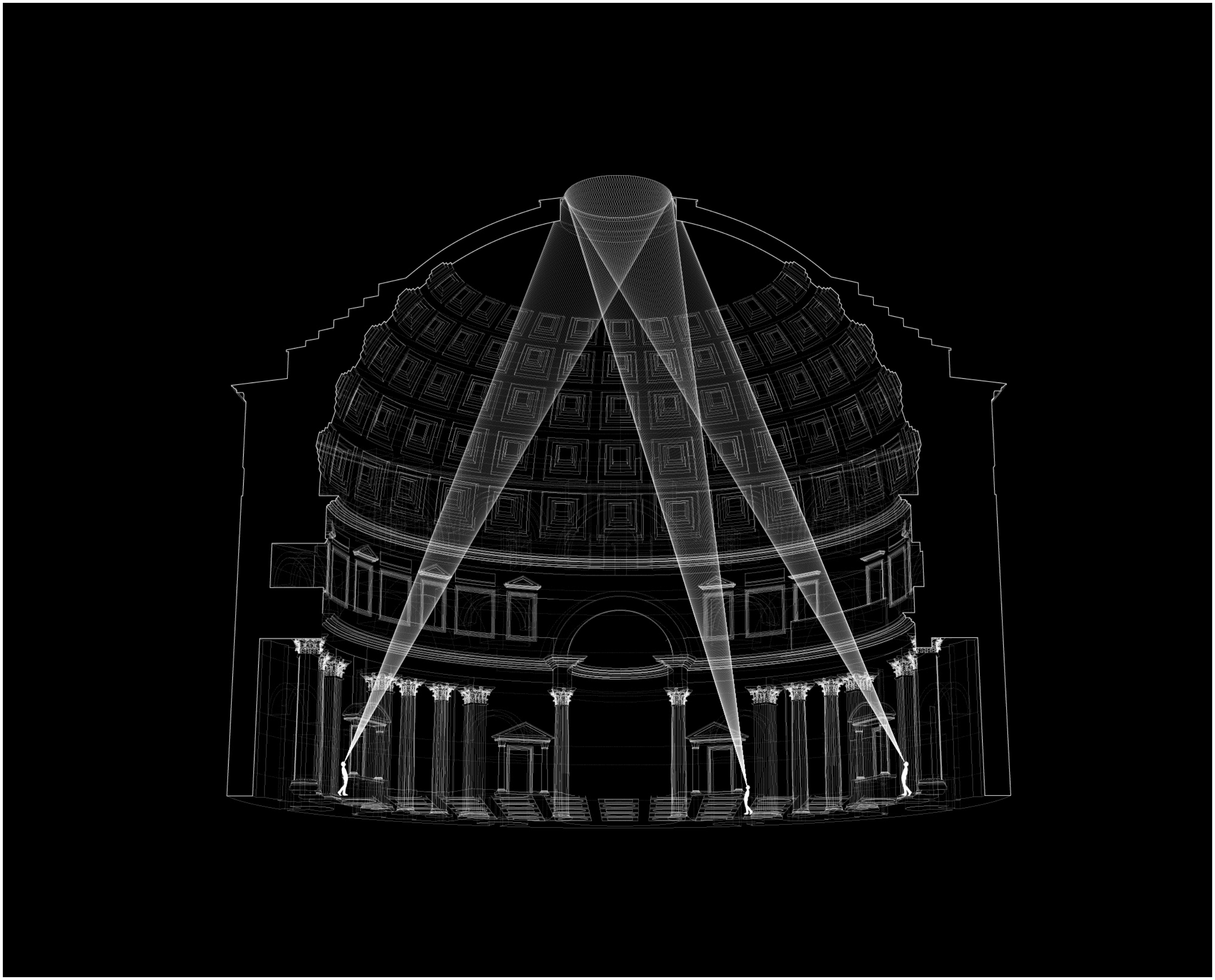


Fig. 3. 3D Cross-section demonstrating three different visitors' perspectives looking up through the oculus. Drawn by Caleb Skene for Kristin Jones Studio.

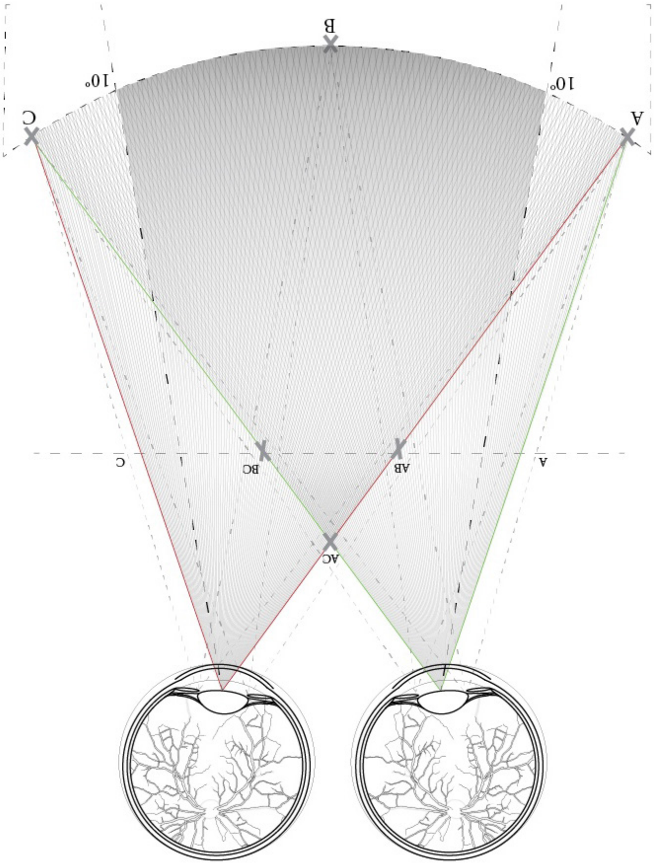


Fig. 4. Stereographic vision diagram showing left eye outlined in red and right eye in green. Drawn by Caleb Skene.

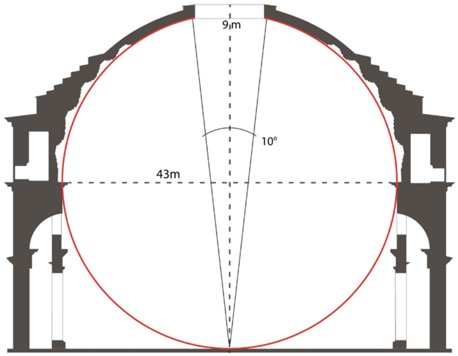


Fig. 5. Diagram showing the visible portion of sky through the oculus after Sparavigna, Dastrù, redrawn by Caleb Skene.

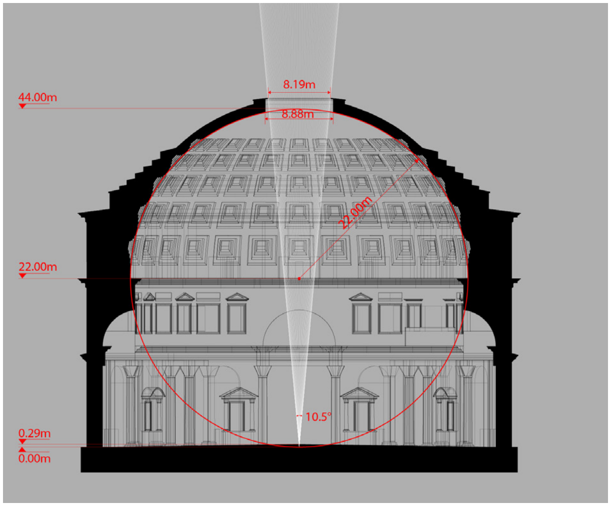


Fig. 6. Dimensioned frontal section showing the geometry of the cone projection into the sky through the oculus drawn by Yuhao Jiang.

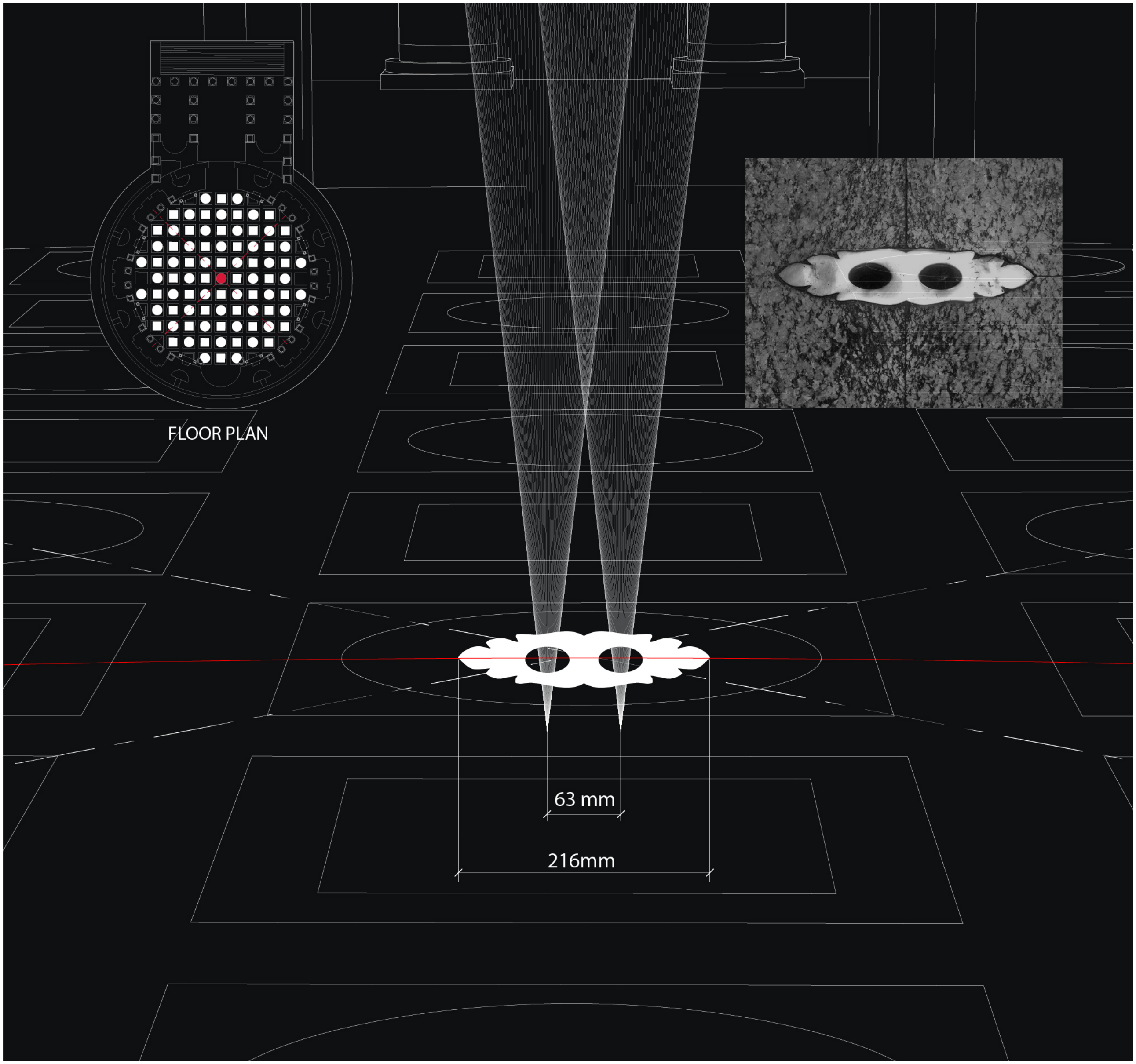


Fig. 7. Diagram of Pantheon's drain cover hypothesized as a stereographic mask with two eye sockets. Drawn by Caleb Skene.

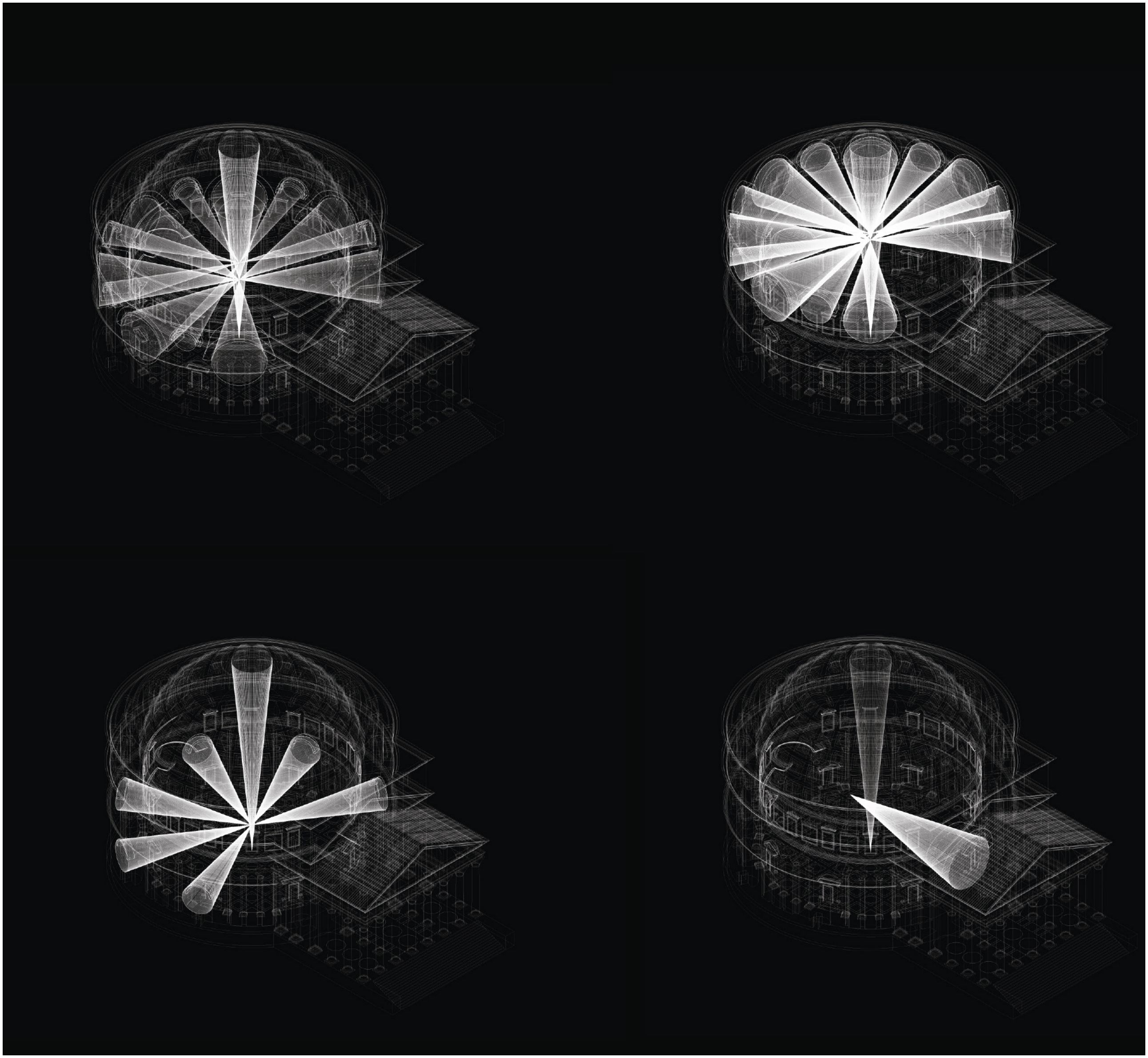


Fig. 8. Invisible cones in the cylinder, generated by all the supporting arches, converging toward the vertical central axis as imagined by artist Kristin Jones and drawn by Yuhao Jiang and Caleb Skene.

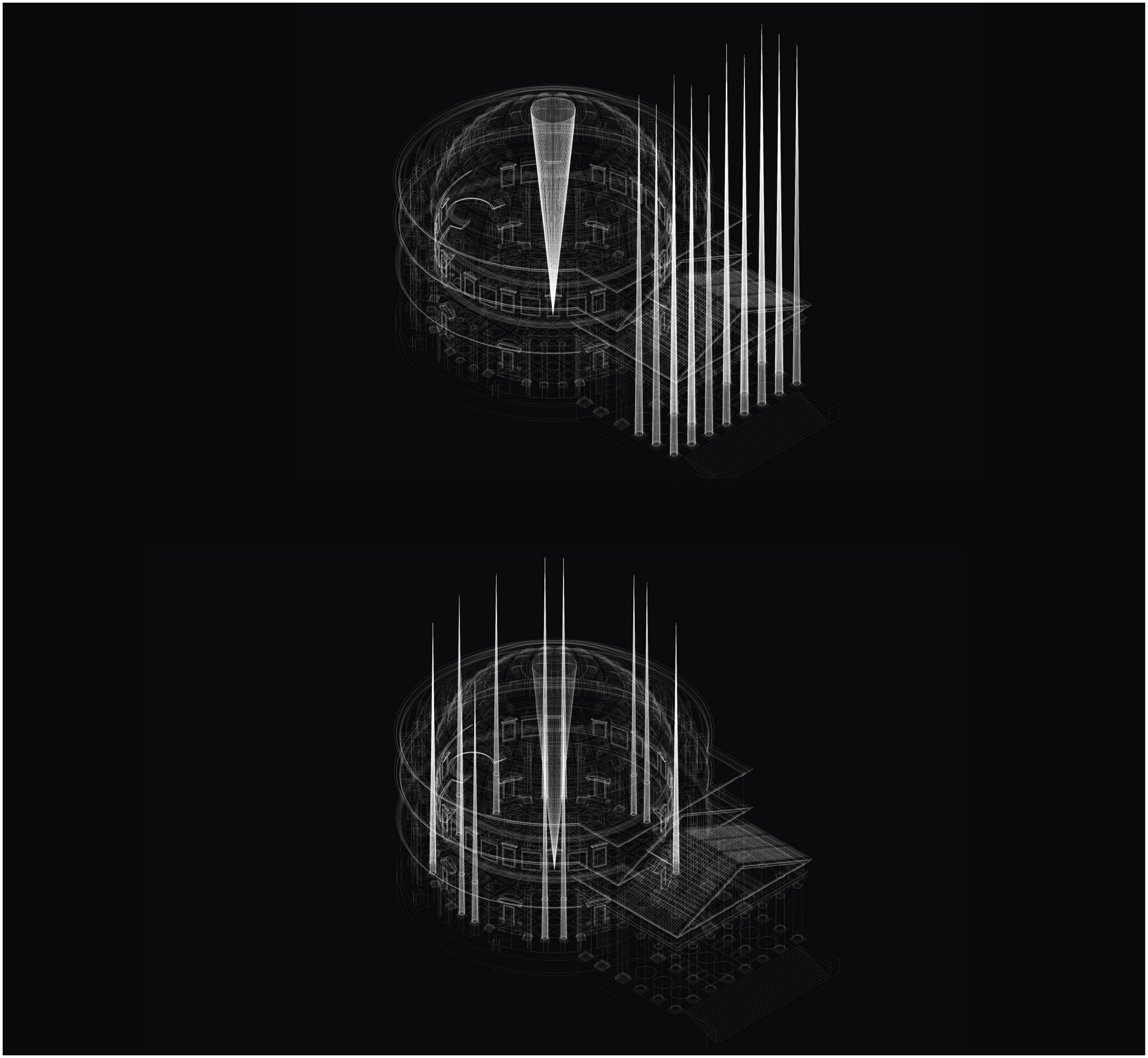


Fig. 9. Invisible cones generated by the vertical taper of the columns as imagined by artist Kristin Jones and drawn by Yuhao Jiang and Caleb Skene.

field –corresponding to the foveal and near-parafoveal regions– for detailed pattern recognition and high-acuity vision [Strasburger, Rentschler, Jüttner 2011]. This narrow conic field, where cone photoreceptors are most densely concentrated, enables sharp and focused visual perception [Curcio et al. 1990]. In the context of the Pantheon's oculus, this 10-degree cone of vision supports the idea that the architectural design may have intentionally framed the viewer's gaze from this central drain cover, channeling attention upward through this focused conic range to emphasize a precise and elevated connection between the observer and the celestial realm above [Silverstein 2008].
Although the intentions of the Pantheon's architect remain unknown, the symbolic equation of the Pantheon with the human eye remains compelling. This interpretation gains further weight when one considers that the Pantheon stands on the traditional site where Romulus was believed to have undergone apotheosis [Coarelli 2014]. Within this symbolic framework, the Pantheon functions as a site of correspondence between mortal Romans and the divine heavens.
As noted earlier, the latent form of the cone manifests itself in the Pantheon by means of the spatial configuration between observer and oculus [1]. However, this is not the only instance of the cone implied by the building's architecture. Indeed, the invisible presence of the cone is to be found everywhere throughout the structure (figs. 8, 9). For example, the relieving arches within the thick walls of the rotunda, curving in three dimensions given the radial construction of the building, delineate a form that can be extended as cones directed towards the center.

Stereographic projection

Another invisible cone reveals itself through examination of the Pantheon's coffering, which has been the subject of much scholarly debate over centuries. While the nested, apparently rectangular indentations on the dome present as rather uncomplicated, this appearance of simplicity is contradicted by in-depth measurements, such as that carried out in 2006 by the Bern Digital Pantheon Project and later in 2015 by architect Mauro Saccone [see: Graßhoffet al. 2009; Saccone 2017].
The coffering has been formed in such a way as to appear to the viewer on the floor of the Pantheon as a series of concentric squares, diminishing regularly in size. Additionally, the design of the coffering allows the central field of each coffer to remain visible to the viewer wherever they may be on the floor of the rotunda. The regular diminution and orthogonal appearance of the coffering is, however, an optical illusion, as the hemispherical nature of the dome requires a warping of these regular geometric shapes to preserve the appearance of regularity [Fernández-Cabo 2013, p. 543]. This is comparable to the way in which columns are sculpted using entasis, as in the case of the Parthenon, for example, so that they appear perfectly straight [2].
While the exact method employed by the builders of the Pantheon to design the coffering has not been precisely identified, there is a strong case to be made for the use of stereographic projection. This technique, first theorized in the context of the Pantheon by Maria Teresa Bartoli in 1995 [Bartoli 1995], involves mapping a two-dimensional, circular design onto a three-dimensional sphere. Once the two-dimensional design has been completed, it is projected from a point at the antipode of the sphere, i.e. the center of projection. In the case of the Pantheon, the center of projection is below the floor of the building [Saccone 2017, pp. 268-272]. This geometric operation was known at the time of the Pantheon's construction, having been detailed by the second-century CE astronomer and mathematician Claudius Ptolemy [Radojevic 2018, p. 8].
A recent hypothesis made Yuhao Jiang, whilst performing a geometric analysis of the Pantheon on behalf of Kristin Jones' *Oculus* project, strengthens the case for the use of this technique. From this analysis a numerical correspondence emerges that links the process of stereographic projection to the diameter of the oculus. Given a sphere, this geometric operation posits a cone of projection, with its vertex originating from an antipode (fig. 10). The cone intersects the equator of the sphere and is extended to the top of the sphere. The resulting large circle, which is the base of the cone of projection, is tangent to the sphere at the antipode opposite the point of projection and will have a diameter of exactly twice that of the sphere. This mapping technique would have allowed the design of the Pantheon's coffering to be laid out in two dimensions, as it would present itself to a theoretical viewer looking up from the point of projection.

With regard to the full-scale drawings, it is interesting to note that a full-scale drawing of profiles for the portico elevation exist etched into the limestone paving in front of Mausoleum of Augustus [Haselberger 1995, fig. 1], no more than 600 meters from the Rotunda.
To create the design of five rows of twenty-eight coffers, this involves dividing the circle "by 28 meridians and enrolling the first circle tangent to the two meridians and the maximum parallel circle, which determines the next parallel's radius. The next circle is tangent on a new parallel and the two meridians and so on" [Radojevic 2018, p. 8].
However, the "maximum parallel circle" mentioned by Radojevic, used to generate the Pantheon's coffering, is not identical with the circle that forms the base of the cone of projection which intersects the rotunda's equator. Rather, to preserve the visibility of the coffers for the viewer standing on the floor of the rotunda, the design is higher than the edge of the larger circle, corresponding to a cone of projection that intersects the sphere of the rotunda slightly above the equator.
This larger circle, while not directly used to generate the design of the coffering, nevertheless provides the key to the discovery made by Kristin Jones and Yihao Jiang. Extending the 28 meridians used to generate the design of the coffering to the full diameter of the larger circle, a smaller circle can be inscribed, tangent to two meridians and the larger circle, in the same process that was used to generate the coffering. This smaller circle, indicated in figures 10 and 11, corresponds directly to the diameter of the oculus.
This correspondence corroborates the proposed theory that stereographic projection was used to design the layout of the dome's coffering. The application was developed for the purposes of mapping the heavens as well as the earth by the astronomer Claudius Ptolemy (c. 100-170), whose life was roughly contemporary with the construction of the Hadrianic Pantheon. While it is perhaps impossible to determine definitively whether this technique was used, Jones and Jiang's findings, as clearly diagramed in figures 10 and 11, point in this direction, reaffirming the works of Bartoli 1995 and Radojevic 2018 and broadening their application of stereographic projection to include consideration of the precise diameter of the oculus.
It should be stressed that other correspondences concerning the dimensions of the oculus have been noted by multiple scholars of the Pantheon. Gert Sperling, in his 1999 monograph on the building notes that the diameter of the oculus is equal to the height of the interior column shafts [Sperling 1999, p. 122]. Additionally, many have identified the diameter of the oculus as one fifth that of the dome [Fernández-Cabo 2013, p. 534].
Both of these correspondences accord well with the principle of *symmetria*. The width of the oculus and the height of the interior column shafts, along with that of the attic story, equate to 30 Roman feet, a measure one fifth that of the diameter of the generative circle of the building at 150 Roman feet. Rather than fixate on individual correspondences between specific measures, the harmony produced by the application of symmetria should be appreciated with reference to the whole.

Other considerations

Given the multiple measurements of the building across time, and accounting for the subsidence and acceptable deviation of the actual building from its ideal, planned form, there is a degree to which "exact correspondences" may be less than exact. Many such correspondences may be found within this margin of error. There is also the problem of knowing what intentions lay in the mind of the designers when determining distances between architectural elements. For example, should measurements of distance be calculated from the center or edge of the columns? How are we to know which of these were employed in the building's construction [3]?
This is not meant to discount these findings, but to highlight the fact that individual discoveries must be taken cum grano salis. Nevertheless, the various possible connections that the oculus has to other aspects of the building's design indicates the inexhaustibility of the Pantheon as an object of study. This work of ancient grandeur has captured the minds of countless scholars throughout the centuries, and they continue to mine its depths to better understand the wonder of its geometry.

The finite and the infinite

Given the enigmatic nature of the Pantheon's design and function, as well as the centrality and importance

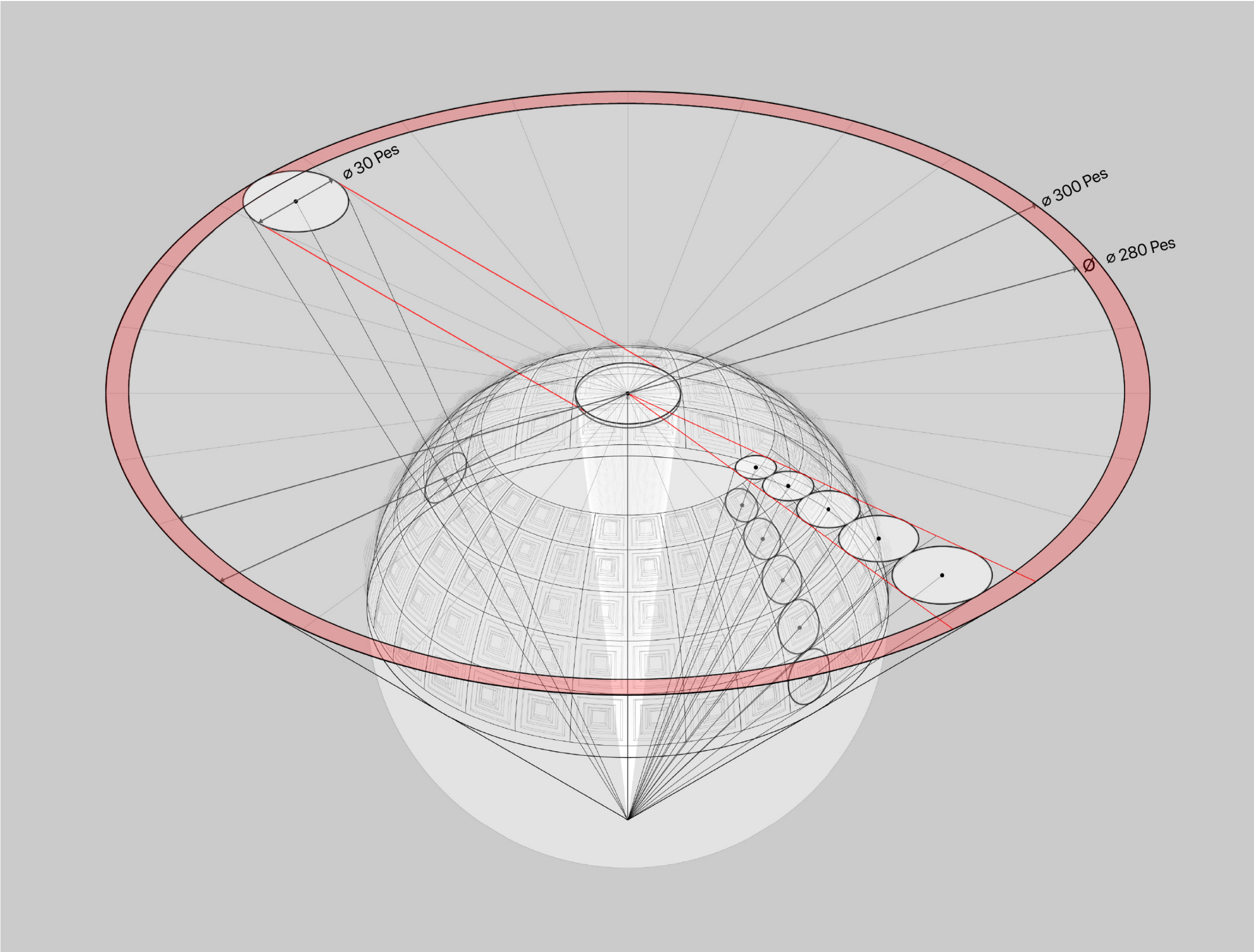


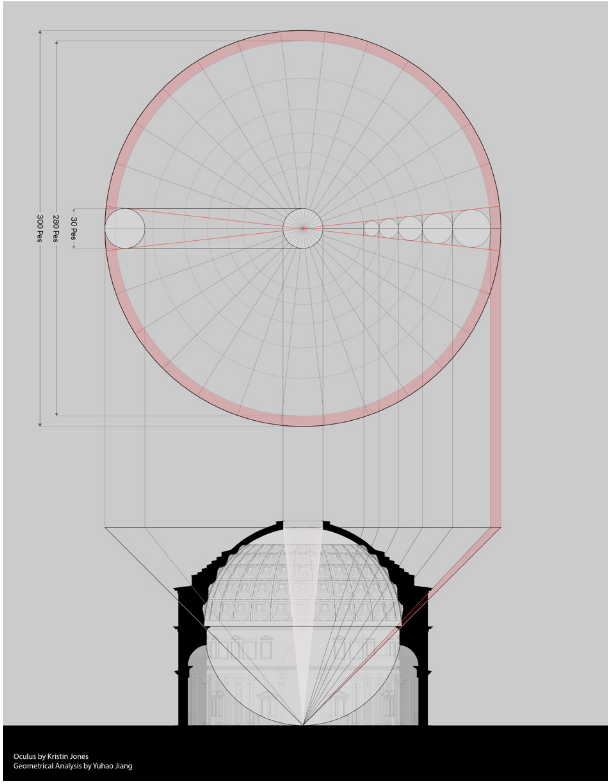
Fig. 10. Axonometric diagram, showing the dimension of the oculus as generated by stereographic projection (drawing by Yuhao Jiang for Kristin Jones Studio).

of the oculus within the plan of the building, it seems likely that its dimensions would correspond to multiple other aspects of the design. The oculus is the point of contact between the microcosm and the macrocosm. By bringing the light of the sun into the otherwise shadowy interior of the building, the oculus may be understood experientially as a point of contact between the realm of the heavenly bodies and the mundane world of the everyday. As Eugenio La Rocca writes in The Pantheon: From Antiquity to the Present: "The oculus in the dome presented that union of earth and sky that symbolized an apotheosis into the heavens" [La Rocca 2015, p. 76].

This aspect of the Pantheon as the link between finite and infinite, between mortal being and immortal cosmos, is distilled in the geometry of the cone. As a geometric figure, the cone connects the finitude of the single point with the relative infinity of the circle. In our vision, the cone is the form in which light reaches us. It underlies the entirety of our visual experience, which is one of the primary ways we encounter the world beyond. In this sense, the cone, like the Pantheon itself, may be understood as emblematic of the relationship between the microcosm and the macrocosm. The implied presence of this invisible geometry within the space of the building, therefore, provides a unique lens through which to understand the elegant symbolism of this ancient wonder (figs. 13-15).

Credits

This article is a collective work by Kristin Jones Studio, with contributions from Nate Sloan, Yuhao Jiang, Caleb Skene, and Brooklyn Richardson.
Special thanks to: Giovanna Spadafora, Mauro Saccone, Christopher Bardt, Daniel K. Brown, Kirila Cvetkovska, Jacqueline Pearse.
The author would like to thank Prof. Giovanna Spadafora not only for translating the text from English into Italian, but also for her constant contribution to the editing of the entire article.



Roman unit	English name	Metric equivalent	Imperial equivalent
Pes	(Roman) foot	0,296 m	0,971 ft
Passus	Pace	1.48 m	4.854 ft

Fig. 11. Plan and Section Diagram of stereographic projection in the Pantheon (drawing by Yuhao Jiang for Kristin Jones Studio).

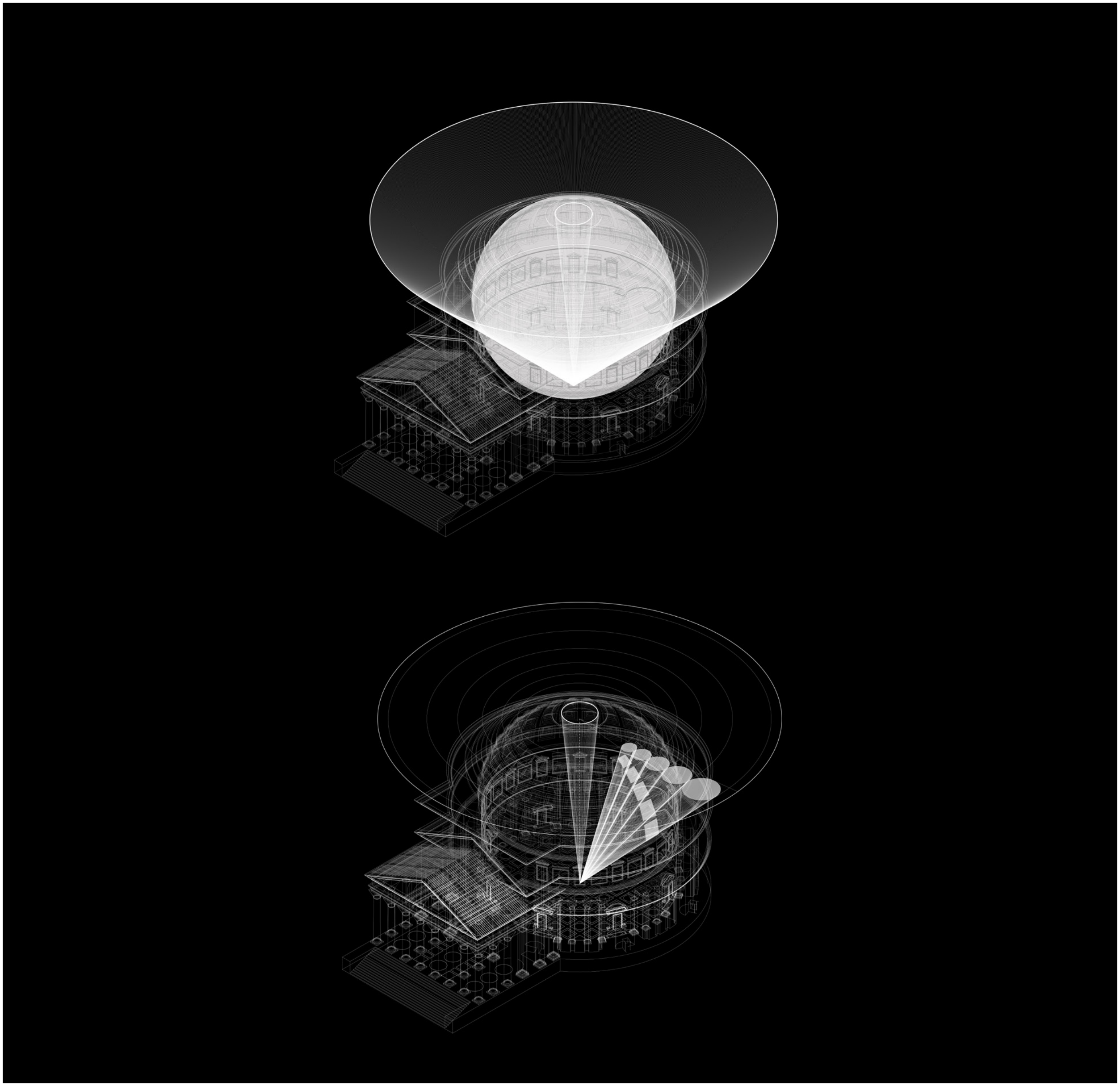


Fig. 12. Diagram of the stereographic projection cones (drawing by Caleb Skene and Yuhao Jiang, 2025).

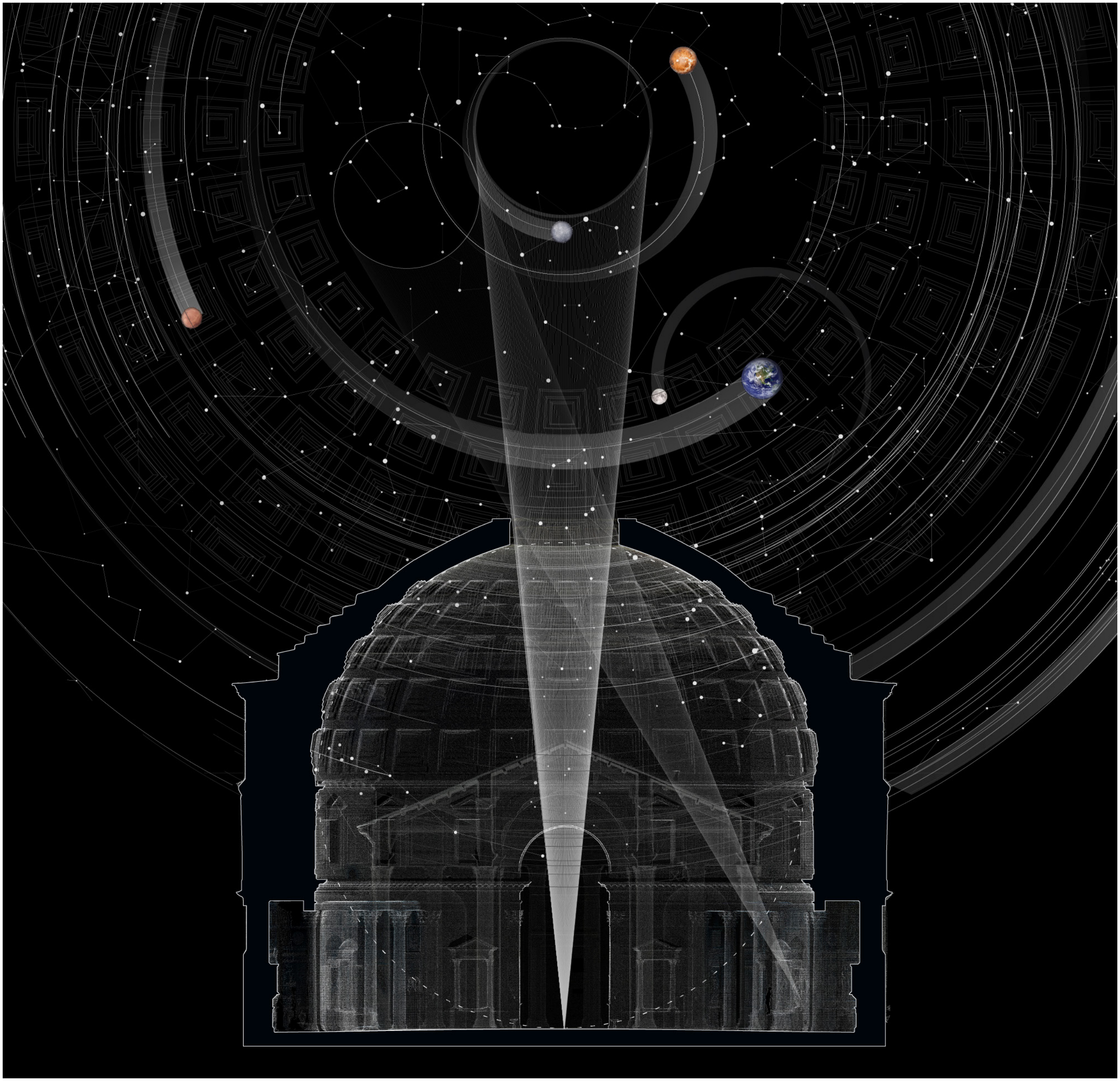


Fig. 13. Diagram of the Pantheon as a link between the finite and the infinite. Drawn by Brooklyn Richardson for Kristin Jones Studio.

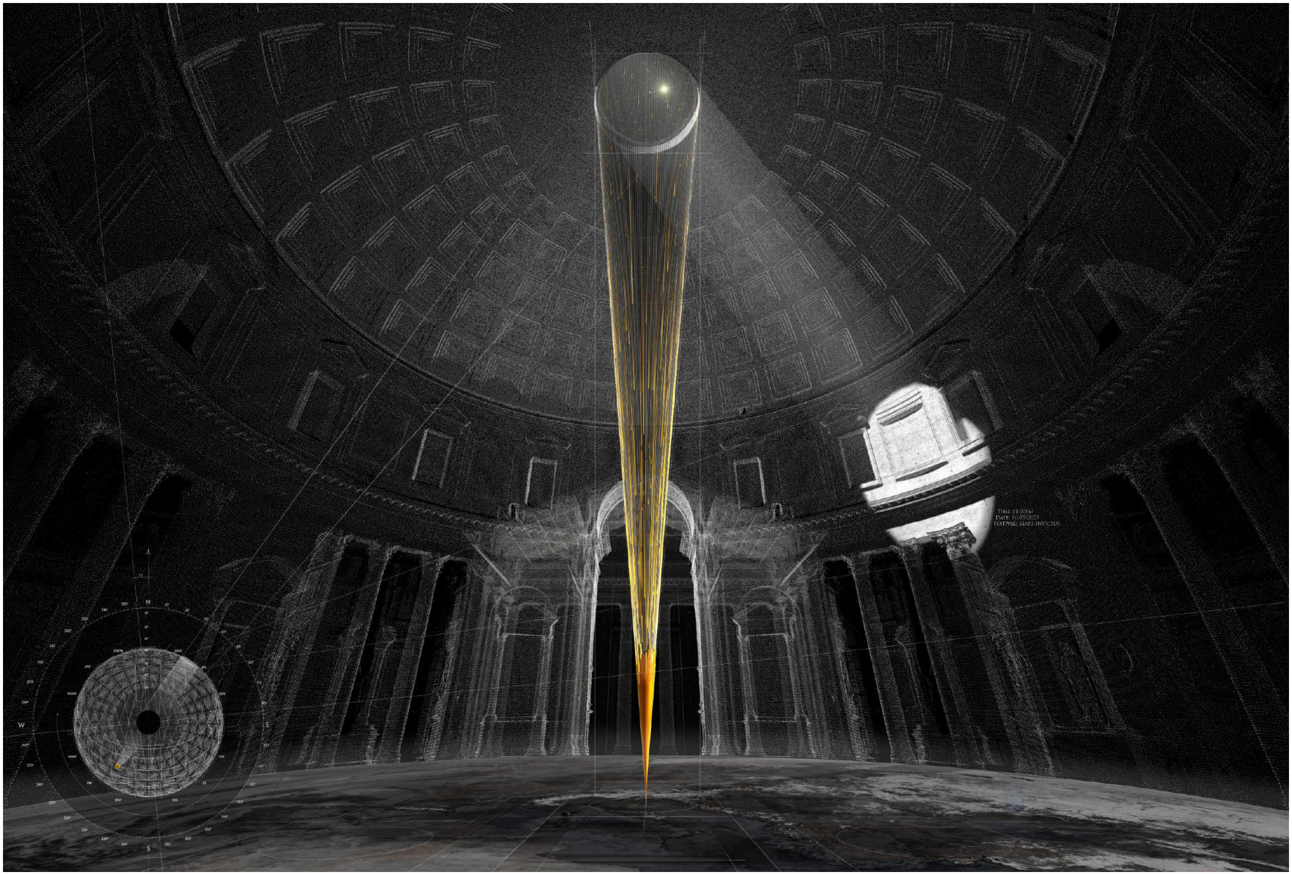


Fig. 14. Mars Invictus, interior view of a moment in time (May 15th) with domed floor and diagram of reflected ceiling plan, showing the position of the sun (drawing by Caleb Skene for Kristin Jones Studio).

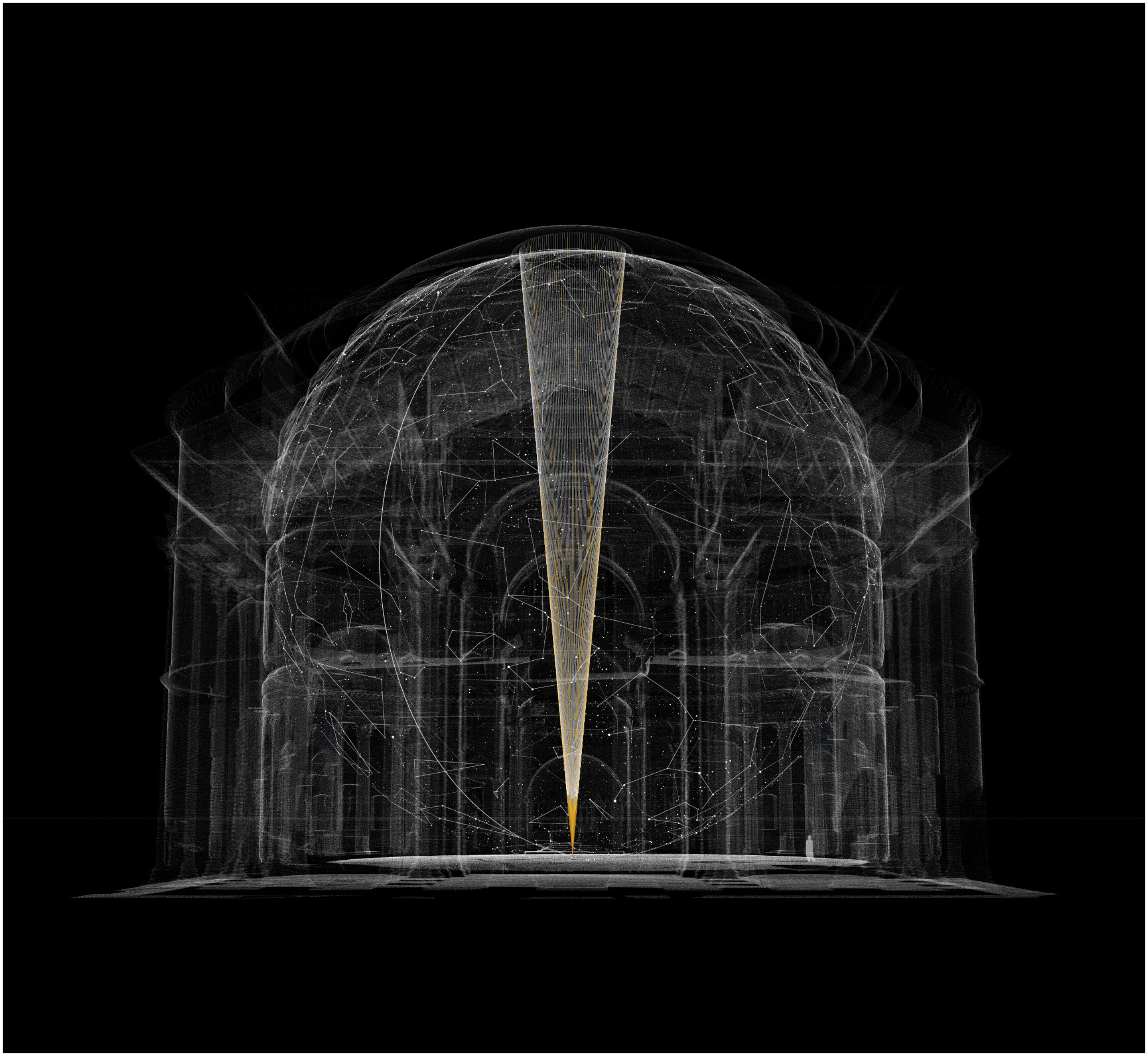


Fig. 15. Vessel of the Cosmos, composition of an approx. 20million LiDAR point model of the Pantheon, with oculus cone and approx.. 9,000-star celestial sphere. Drawn by Brooklyn Richardson for Kristin Jones Studio.

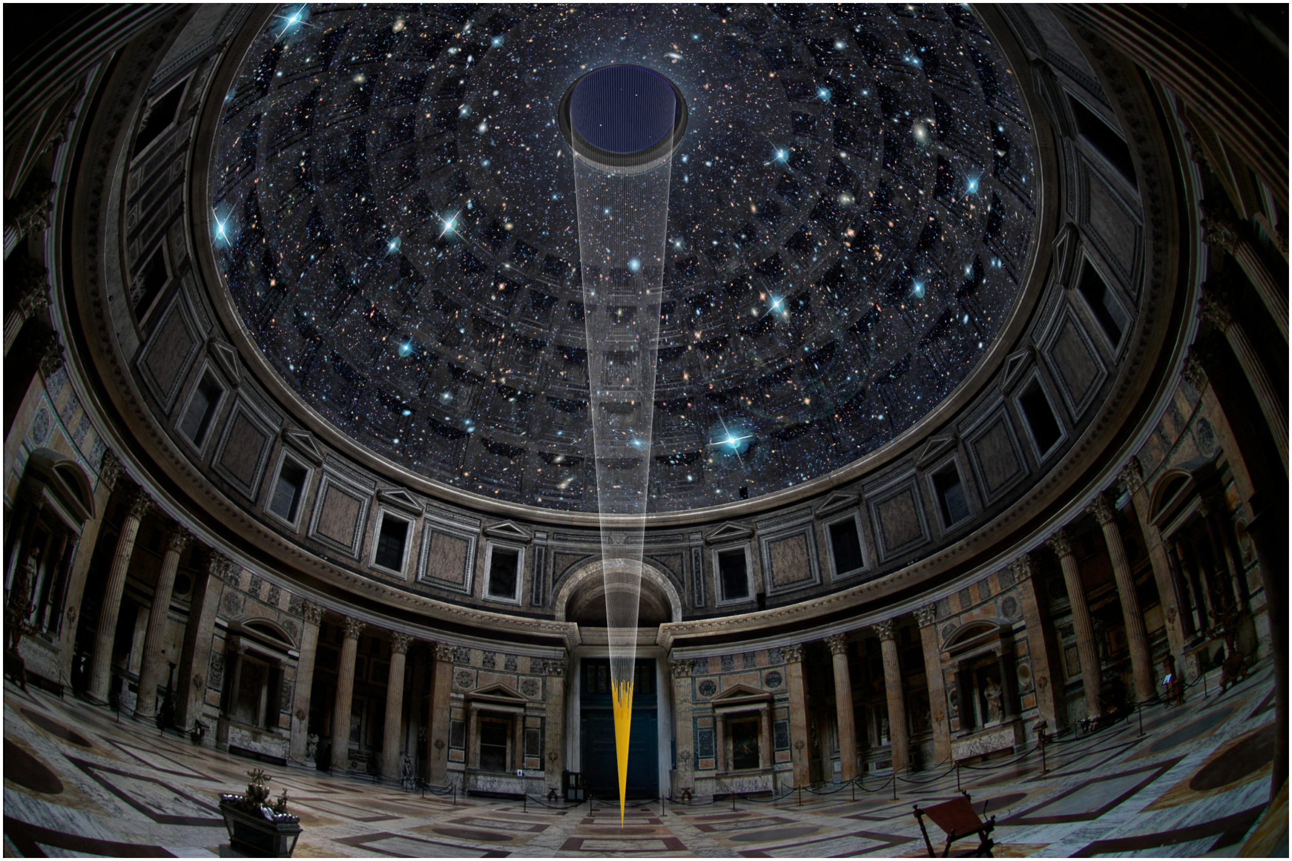


Fig. 16. OCULUS. Nighttime view from altar (rendering). Installation composed of three elements: cone form, projection and sound. Cone of thread envisioned by Kristin Jones descends 150 feet from the 30-foot oculus. The projection is a Deep Field image, including over 300,000 distant galaxies, millions to many billions of light-years away, composed by Michael Benson from digital images collected with the CFHT telescope between 2003-2009.

Fig. 17. OCULUS. Daytime view from altar. Concept and Art Direction: Kristin Jones. Original Image: Marcello Melis. Geometric Analysis and Drawing: Yuhao Jiang.

Notes

[1] It should be stressed that while the geometric configurations described above are all cones, they differ in their specific aspects of height, apex etc.

[2] Entasis is an optical device by which the shaft of a column is sculpted so that its vertical profile appears slightly convex. If sculpted perfectly straight, the column would appear to diminish in width at its midpoint. Entasis serves to correct this illusion. It should be noted, however, that in some cases its use extends well beyond the correction of an optical illusion and is motivated by its intrinsic aesthetic value: see Jones 1999.

[3] This problem, at play in all the Romans' radial buildings, is explored more fully in Jones 1989, pp. 106-151.

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Geometric Evolution of Structure in the Gothic Architecture of Guillem Sagrera in Perpignan. Graphic Analysis

Luis Agustín-Hernández, Aurelio Vallespín-Muniesa, Marta Quintilla-Castán

Abstract

Guillem Sagrera is an essential architect during the 15th century in the Crown of Aragon. He is known for his participation in the construction of Mallorca Cathedral, first as an apprentice in the Portico del Mirador, from 1397 and later as a teacher. He was also commissioned to build the Lonja (Maritime Exchange) in Mallorca, begun in 1426. In this period his residence in Perpignan is documented, at least from 1410, but there are certain unknowns about the works in which he may have participated in Roussillon during this period, such as his part in the Lonja del Mar, in Perpignan or the chronology in the works of the chapterhouse of Saint John the Baptist. This period influenced and modified the way of conceiving the geometric layout of the structure in his buildings. This study aims to determine two aspects: 1. Through the parallelisms in his sculpture, to determine the works that he was able to carry out in this period in Roussillon. 2. Once his participation in the Chapterhouse of Saint John the Baptist was confirmed, to carry out a deep graphic analysis, modelling the architectural space, in which the structural and geometric experimentation is confirmed, observing how there was a change from the southern Gothic layout, eliminating capitals and corbels, to a freer layout with a mastery of the geometric layout, going beyond the canons and how this would be reflected in two of his later works, the Lonja de los Mercaderes in Palma and the Sala dei Baroni, in Castell Nuovo in Naples.

Keywords: Mediterranean Gothic, digital model, Guillem de Sagrera, Saint John the Baptist Perpignan, Lonja del Mar Perpignan.

Introduction

Guillem Sagrera was born in Felanitx, on the island of Mallorca, around 1380 and died in Naples in 1454. In 1397 he is mentioned for the first time receiving a daily wage as an apprentice in the Portal del Mirador of Mallorca Cathedral [Alomar 1970, p. 51], this beginning is important, because the influences of the masters with whom he worked are key to understanding his development and his works.

Sagrera and his work as a sculptor

In 1396, [Teres 2011, p. 174] the master Pere de Santjoan began to direct the work on the Portal del Mirador, replaced, after his death, by Pere Mora. Other masters such as Henry the German [1] and John of Valenciennes [2] also participated. It should be noted that in these years, during the reign of John I, there is an approach to French culture due to marriage exchanges [Teres 2011, p. 150]. The influence was not surprising in Palma due to the temporary independence of the Kingdom of Mallorca from the Crown of Aragon. Sagrera's first influences come from the northernmost Gothic architecture, known as the Burgundian Gothic, from the court of the Valois in Dijon.
At that time Claus Sluter was commencing a new style with his best-known work, the Well of Moses, questioning the Flemish sculpture of the time, represented in Cathedrals such as Amiens, where the slender figures are delicate and curved imitating ivory, with soft folds.

In the Well of Moses the figures are detached from their Gothic frames, they are no longer slender, the clothes are depicted in a direct way with deep folds, concealing the entire body except for the hands and the head. The hands have movement, while the expressions of the faces become portraits.

Guillem Sagrera was the master of the Mallorcan Cathedral from 1416 to 1435 [Alomar 1970, p. 115]. During those years, the fourth and fifth sections of the naves, the chapterhouse and sculptural work were carried out. In the Portico del Mirador the figure of Saint Peter is attributed to Guillem Sagrera, in a document written around 1422 (fig. 1) where: "he has surpassed the style he learned from John of Valenciennes, working to approach the style of Sluter" [Alomar 1970, p. 94]. Due to stylistic similarity, the figure of Saint Paul is also likely to be his work, including the figure next to him of Saint Anthony, due to the Tau-shaped crosier (fig. 1). Of the 4 figures that adorn the portico, that of Saint John the Baptist is the one that seems different, it is less realistic from the point of view of the expressiveness of the face, moving away from the aesthetic principles pioneered by Claus Sluter.

Several years later, in 1426, worked started on the Silk Exchange [3]. Of all the sculptural repertoire that appears in it, according to Alomar [Alomar 1970, p. 131], we can confirm that Sagrera was responsible for very few pieces, albeit very important ones, such as the angel on the façade of the square, the Saint John the Baptist on the corner, and the Madonna and Child located at the west gate of the garden, made between 1430 and 1440. Looking at the image of the Madonna (fig. 2), we can see influences from Claus Sluter. Alomar compares it to Sluter's Moses because of her clothing. Without a doubt, the expressiveness of the Madonna's face, despite the deterioration of the sculpture, is remarkable and approaches the expressiveness of the Flemish master [Alomar 1970, p. 88]. The angelabove the Madonna is more original, with its upside-down position and its bare legs. Its head recalls the angel of the annunciation of the birth of Saint John to Zacharias, one of the few original plinths that are preserved of those made by John of Valenciennes in Bruges City Hall.

Fig. 1. Guillem Sagrera. Statues of Saint Peter and Saint Paul, Portal del Mirador, Mallorca Cathedral (photograph by the authors).

Fig. 2. Guillem Sagrera. Statue of the Virgin on the Garden Gate and Saint John the Baptist, Lonja de los Mercaderes (Silk Exchange), Palma de Mallorca (photograph by the authors).

Fig. 3. Guillem Sagrera. East facade, Lonja del Mar, Perpignan (photograph by the authors).

The figure of Saint John the Baptist (fig. 3) is reminiscent of the figure of Isaiah in Sluter's Moses' well, not only because he frees himself from the niche on which he stands, but also because he has similar features, while the depth of his clothes is reminiscent of the Flemish master, especially that of the sleeve that leaves the arm bare with great naturalism.

Sagrera in Perpignan

Sagrera's first years in Perpignan
Sagrera is documented for the first time in Perpignan, in 1410, credited together with Rotli Vautier [4], for the pulpit that has now disappeared from the church of the Franciscans, a document made known by Pierre Vidal [Alomar 1970, p. 86]. That same year, he appears as executor of the will of a stonemason and appears as "architect, Peyrer, from the city of Mallorca, living in Perpignan" [Alomar 1970, p. 90]. In 1411 he appears in a professional document together with Rotli Vautier, Jean de Liho, from Brussels and the carpenter Leonart Raholf [Alomar 1970, p. 90]. This confirms his relationship with Flemish masters in this period.

In 1416, Guillem Sagrera was consulted about the change of plan for the Cathedral of Girona [5] in his capacity as master builder of Saint Jean le Neuf de Perpignan, so it is certain that in that year he was the master builder of the latter Cathedral [Alomar 1970, p. 90].

It is not known on what date he left Mallorca to travel to Roussillon; it has been suggested that it could have been around 1410, because his presence in Perpignan that year

is documented [Alomar 1970, p. 90]. One hypothesis may be that it was together with Pere Santjoan, whose presence in Elna 1404 and in Perpignan in 1406 is documented [Sabater 2010, p. 301], and there is evidence that they worked together on the Portal del Mirador.
Alomar says that around 1416 his trips to the court of Dijon, ruled by the Dukes of Burgundy, must have been continuous in order to learn from the Flemish masters and follow in the footsteps of Claus Sluter [Alomar 1970, p. 92]. There seems to be no doubt about Sagrera's trips to Dijon, due to the influence on his pieces from the second decade of the 15th century, the question is when he was able to make these trips. If we accept the hypothesis that Sagrera resided in Roussillon from around 1405, it is possible to argue that these trips to the North intensified in these early years of the 15th century, a period in which his activity is also unknown.
Sagrera's relationship with Rotli Vautier is also unknown. His presence in Perpignan between 1410 and 1432 is documented [Catafau 2018, p. 201], Alomar states that he may have acted as Sagrera's deputy in his works in Roussillon, during that period in which Sagrera alternated his residence between Mallorca and Roussillon, as well as making his own works [Alomar 1970, p. 90] [6]. It is important to determine until what year he carried out these tasks, Alomar, as has been said, says it was until 1432 but also states that between 1427 and 1430 Vautier worked as a teacher in Girona Cathedral. Later it is known that he worked in Barcelona in the cloister of the Cathedral, so at least in 1432 he was in Barcelona. Finally, from 1436 until he died in 1441 he worked on Lleida Cathedral. So it seems that it is likely to have been until 1427 or until 1430, given the proximity of Girona, when Rotli Vautier could have worked as Sagrera's deputy.

The Loge de Mer in Perpignan and its sculptural ensembles
Una orden real de 1397 autorizó la construcción de la A royal order in 1397 authorized the construction of the Loge de Mer, [7] by the Consulate of the Sea, founded in 1388, as a commercial institution attached to the town council [Poisson 2011, p. 87]. The work began in 1402, and was completed in the first quarter of the 15th century. In 1540, the building was enlarged due to the importance of the ports of Collioure and Canet. The extension with two other sections in 1540 gave rise to certain doubts on the north façade about the treatment of the decoration of the original project and its extension [8]. The researcher Tina Sabater raises

Fig. 4. Guillem Sagrera. Saint Bartholomew (left window, East facade) and Prophet (left window, North facade), Lonja del Mar, Perpignan (photograph by the authors).

the possibility that Sagrera and Vaulter worked on it, apart from the chronological coincidences, both masters worked with the stone of Fonts, a type of stone used in the medieval section [Sabater 2010, p. 302].
Sagrera's work on the Loge would be carried out in the period between 1410 and 1415, so this relates to the eastern façade and occasionally to the north. This building has undergone several renovations, also with regard to decoration, as indicated [Poisson 2020, pp. 142-144]. On the eastern façade, in addition to the figure of Saint John located between the two arches, the right window is preserved, while in the case of the left window only the outside of the wall is preserved, the plant decoration of the edge of the waterspout that is topped off with two sculptures at the height of the capitals and the lower decoration of the sill. In the two windows of the north façade, only the lower decoration of the sill is preserved.
The four sculptures on the eastern façade that top the plant decoration of the waterspout rim are the most unique items of the sculpture of this building, where the Burgundian style for the folds and hair suggests a general connection with Sagrera [Poisson 2020, pp. 142-144] (fig. 4). The sculpture located to the right of the left window depicting Saint Bartholomew [Sabater 2010, p. 298] (fig. 5) should be highlighted for its quality and state of conservation. The serene expressiveness of his face and the delicacy of his hands, as well as the depth of relief of his garments, are reminiscent of Sagrera. The treatment of the sleeve of the right arm is reminiscent of that of the same arm of Saint John of the Mallorca Maritime Exchange.


Fig. 5. Vautier. Saint John the Baptist, East facade of the Lonja del Mar; Keystone, Chapter House, Cathedral of Saint-Jean-Baptiste, Perpignan (photograph by the authors).

In the first section of the north façade there are also sculptures called "Sagrerian", that is, of marked expressiveness like those of the Burgundian school [Sabater 2010, p. 302]. Two pieces of the ends stand out, in the lower part of the sill of the first window of the north façade, where a prophet and an angel can be seen (fig. 5).
The expressiveness of these figures is remarkable, despite their size. The prophet, again, by the expressiveness of his face, is reminiscent of Saint John of the Lonja de Mallorca. This was probably the work that led Sagrera to become the master builder of Perpignan Cathedral and participate in the Girona consultation.
As has been shown, in the sculpture of Guillem de Sagrera a significant influence can be identified of the artists of the Burgundian court, which would modify and develop his style. In the same regard, it is intended to establish the evolution that his way of conceiving space and its architectural traces would undergo during his stay in Roussillon and which, as will be seen, comes from the same influences as sculpture, emphasizing the originality of the author as he received influences that were significantly different from the rest of the builders who worked in the lands of the Crown of Aragon. This learning, with a great personal contribution, will be experienced in the Chapterhouse of the Cathedral of Saint John the Baptist. A small room, low in comparison with the building and of relative importance on the whole, located beyond the buttresses of the apse. Without a doubt, the right place to experience a different way of conceiving the Gothic structure. The result is a magnificent room, where the ribs of the vaults merge with the column and the pre-existing buttresses, eliminating capitals, fasciculated columns with mini-columns and corbels, facilitating freedom of design and lending dynamism to the result. The experiences gained were transferred and developed in his later works: the Lonja de Mercaderes (Maritime Trade Exchange) in Mallorca and the Sala dei Baroni in Castelnuovo in Naples. This would influence other architects such as Pere Comte in the Silk Exchange in Valencia or much later Antoni Gaudí in Park Güell.

Methodology of the analysis

A graphic survey was necessary to carry out the analysis. "Surveying must be fundamentally a method of analysis and its final goal has to do fundamentally with the knowledge of the building" [Almagro 2004, p. 14]. To carry

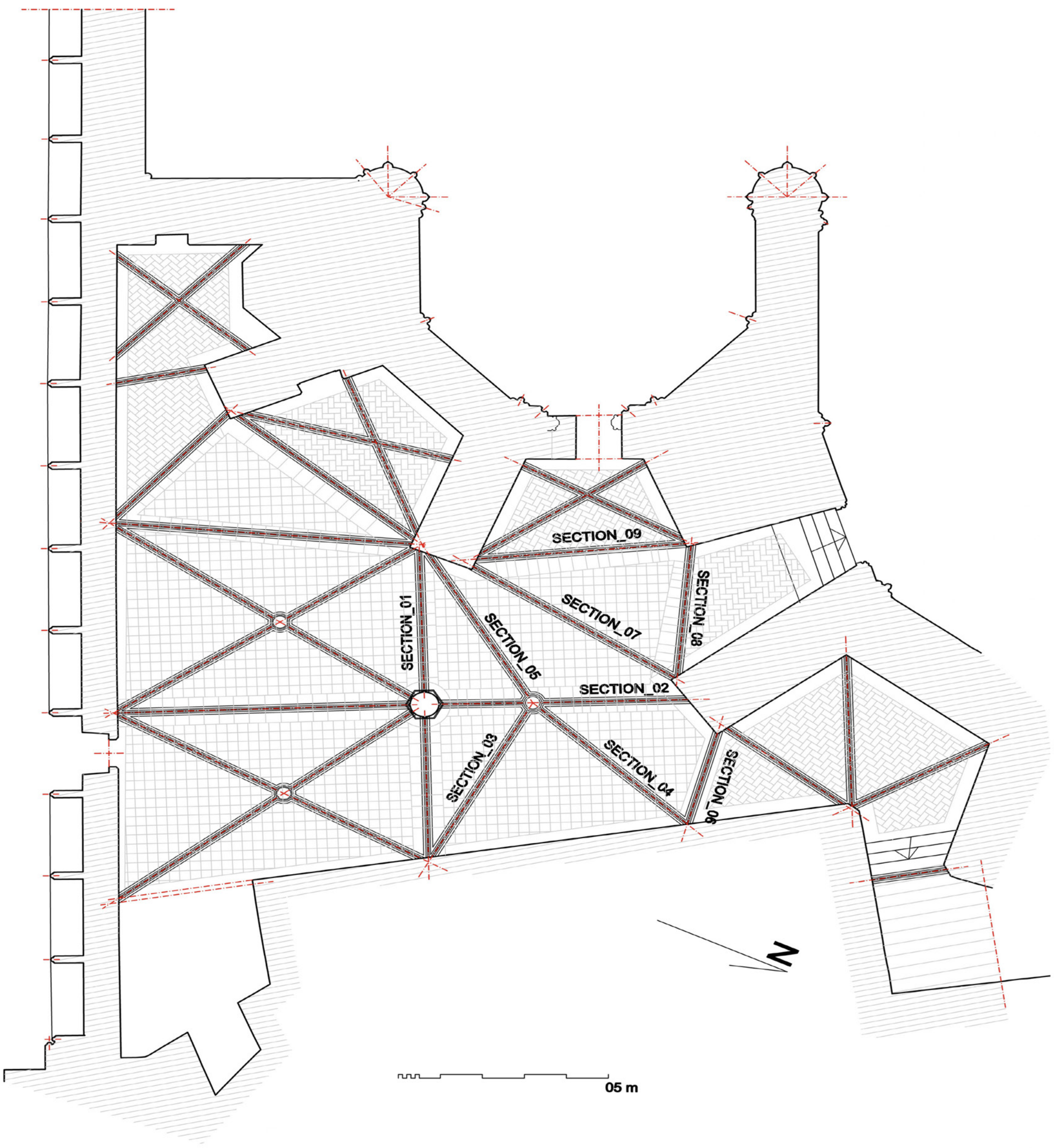

Fig. 6. Guillem Sagrera. Floor plan of the Chapter House, Cathedral of Saint Jean Baptiste, Perpignan (graphic elaboration by the authors).

Fig. 7. Guillem Sagrera. Central column, Chapter House, Cathedral of Saint Jean Baptiste, Perpignan (photograph by the authors).

out this work and to be able to show the structural experimentation, a graphic analysis of the whole ensemble was carried out, firstly, a point cloud was made, with millimetric precision, using a laser scanner (LS), with which great accuracy is guaranteed, it is a very suitable technique for spatial analysis.
The tool used was a Faro Focus S70 laser scanner, measuring between 0.6 m and 70 m, with sensors: GPS, compass, altimeter, dual-axis compensator, and distance accuracy of up to ±1 mm, including HDR photographic overlay. With the point cloud obtained, the analysis was performed using 2D CAD software, Autocad from Autodesk and BIM software ArchiCAD from Graphisoft. "The graphic survey of the heritage site necessarily involves obtaining a three-dimensional digital replica of the highest precision and graphic quality. We will obtain this three-dimensional model by means of SfM (Structure from Motion) photogrammetry and/or 3D laser scanner" [Rodríguez-Navarro, Gil-Piqueras 2024, p. 557].

Study of the chapterhouse

Chronology and designers of the chapterhouse
Ponsich identifies Sagrera for the first time as the architect of the chapterhouse of the 'future' Cathedral of Saint John the Baptist and claims that it was probably built between 1433 and 1447, without providing data [9]. Alomar says that if the historical reasons for this attribution are satisfactory, the stylistic ones are decisive [Alomar 1970, p. 110]. Sabater disagrees with this date and says that it would have been logical for Sagrera to take on this commission between 1410 and 1415 [Sabater 2010, p. 305]. This would justify his presence in Girona in 1416 as master builder of the Cathedral, and provides further evidence in sculptural terms, namely the similarity between the Saint John the Baptist on the façade of the Lonja del Maritime Exchange in Perpignan by Rotli Vautier and the Saint John the Baptist on the keystones of the chapterhouse (fig. 6).
The keystone of the most exceptional vault, with 5 ribs, has a figure of Saint John the Baptist, against a background with the bars of the Crown of Aragon, with a facial expression reminiscent of that of the Maritime Exchange. If it is assumed that Vautier worked as Sagrera's deputy in his works in Roussillon and that he designed this keystone, he must have done so before 1427 or 1432, dates on which it has been indicated that he left Roussillon, therefore questioning Alomar's theory that the Chapterhouse was built from 1433 onwards. In no case does any author cast any doubt on Sagrera as the designer.

The chapterhouse from the perspective of its architectural lines
The space of the chapterhouse is unique due to the geometry of its floor plan (fig. 7) Sagrera tackles a complex problem, resolving the covering of a room, adapting

Fig. 8. Guillem Sagrera. Zenithal view, Chapter House, Cathedral of Saint Jean Baptiste, Perpignan (graphic elaboration by the authors).

the curved geometry of the apse of the Cathedral and its buttresses, with the straight geometry of the boundary with the cemetery, also respecting a background that was narrowly constrained by the property, also with a straight geometry. The solution is a brilliant one, in contrast with a more homogeneous and patterned geometry, such as the chapterhouse that he himself built those same years in Mallorca Cathedral.

To resolve the geometry of the structure, he placed a single column at approximately at the centre of the space, from which he projected ribs to the irregular edges that delimit the room, forming pointed arches of different lengths, as detailed in the study of the vaults, but with an approximately constant curvature in practically all its arches.

The column, an essential element of the space, has a base of hexagonal section. In his later designs this base would be lost, with an approximately cylindrical shaft travelled by the vertical prolongation of the ribs of the arches, located in general in the projection of the centre from the sides of the hexagon, although in other cases it also coincides with its vertices, maintaining a sound respect for proportion and geometry. The most outstanding thing about this column is that it lacks a capital, this absence is not only for aesthetic reasons; it has a geometric justification (fig. 8).

In later designs such as the Mallorca Maritime Exchange, they were threaded around the column, eliminating not only the capitals but also the bases. In the same way that the capital disappears, the corbels disappear at the point where the arch and the wall meet, embedding themselves in it, except in one case, which will be studied later as it is so different. This innovative solution may have been inspired by the cloister of the unfinished Narbonne

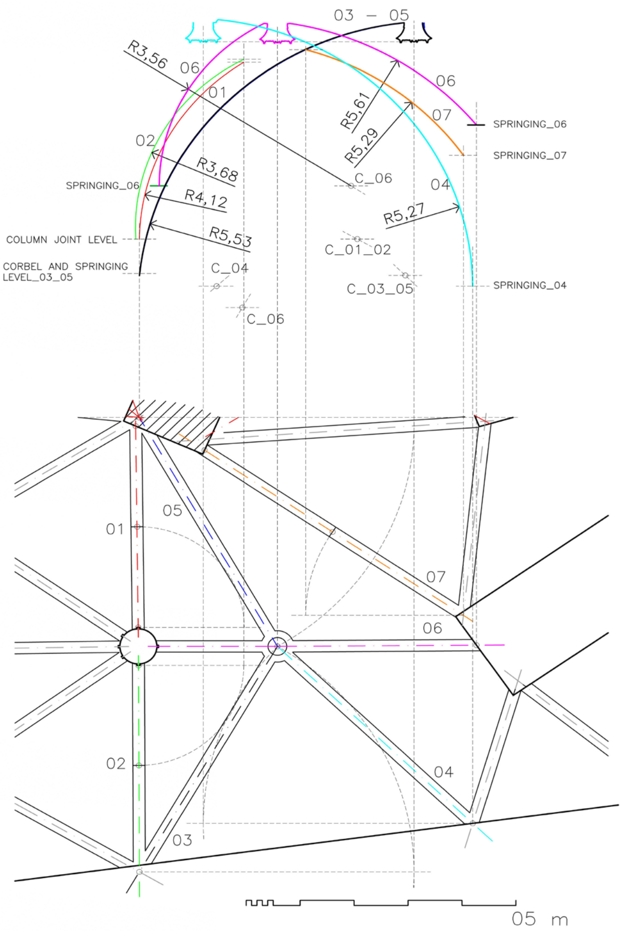

Fig. 9. Guillem Sagrera. Tracery of the irregular pentagonal vault, Chapter House, Cathedral of Saint Jean Baptiste, Perpignan. Fold-out of the arch tracery onto a vertical plane for true magnitude projection, based on Viollet-le-Duc's interpretation of Villard de Honnecourt's drawings and disseminated by Enrique Rabasa and José Carlos Palacios, among others (graphic elaboration by the authors).

Cathedral, whose construction began around 1360, or in the Theology Room of the Palace of the Popes in Avignon, or the Palace of the Dukes of Burgundy in Dijon, which, as has been shown with the influence on his sculptural work, he must have known about during his stay in Roussillon, but in the case in hand he gives this solution a greater structural sense.

To cover this space leaning on the central column, he devised three coverings, two classical vaults supported on the wall of the cemetery and the column, a regular solution, geometrically parallel and with the predominant curvature in the room of approximately 5.50 m, three trapezoidal, with considerable symmetry in the openings of the buttresses of the Cathedral, with different curvatures and an irregular pentagonal vault, which will allow it to resolve geometric disagreements and the main object of the study, due to its uniqueness (fig. 9).

This vault features varying spans and a consistent curvature –approximately 5.50 m– for the arches meeting at the keystone, with the exception of the shortest arch, which has a radius of 3.56 m. In contrast, the arches springing from the pier that do not reach the keystone (formerets 1 and 2 in fig. 9) exhibit different curvatures, measuring 4.21 m and 3.68 m, respectively. The arches that form this vault must have different heights; as they must be joined in a keystone of fixed height, the starting level of the arch must be lowered, which rules out having capitals or corbels at the same level. Despite the aesthetic disadvantage, it could be done from a structural point of view, but when they converge on a pillar, as is the case of Saint John the Baptist, it is not feasible (fig. 9).

It is here, at this time, where the capital and, by symbiosis, the corbels disappear, starting the arch directly from the walls. This solution, from a structural point of view, is more straightforward: the capital, in traditional lintelled architecture and semicircular arches has the task of centring loads on the pillar; whereas in Gothic architecture with pointed arches it would not perform this function because the lateral thrusts are much lower and the load is practically vertical, the capital behaving as a stylistic ornament.

For the study of the pentagonal vault, a graphic analysis was carried out on the 3D model, with flat sections, observing curvatures, the arch starting point, the centre of each arch and the geometry itself (fig. 10); where it can be observed through drawing, why the geometric decisions of the layout of arches were made, which might seem

Fig. 10a. Guillem Sagrera. Cross-sections of the pentagonal vault arches, Chapter House, Cathedral of Saint Jean Baptiste, Perpignan (graphic elaboration by the authors).

Fig. 10b. Guillem Sagrera. Cross-sections of the pentagonal vault arches, Chapter House, Cathedral of Saint Jean Baptiste, Perpignan (graphic elaboration by the authors).

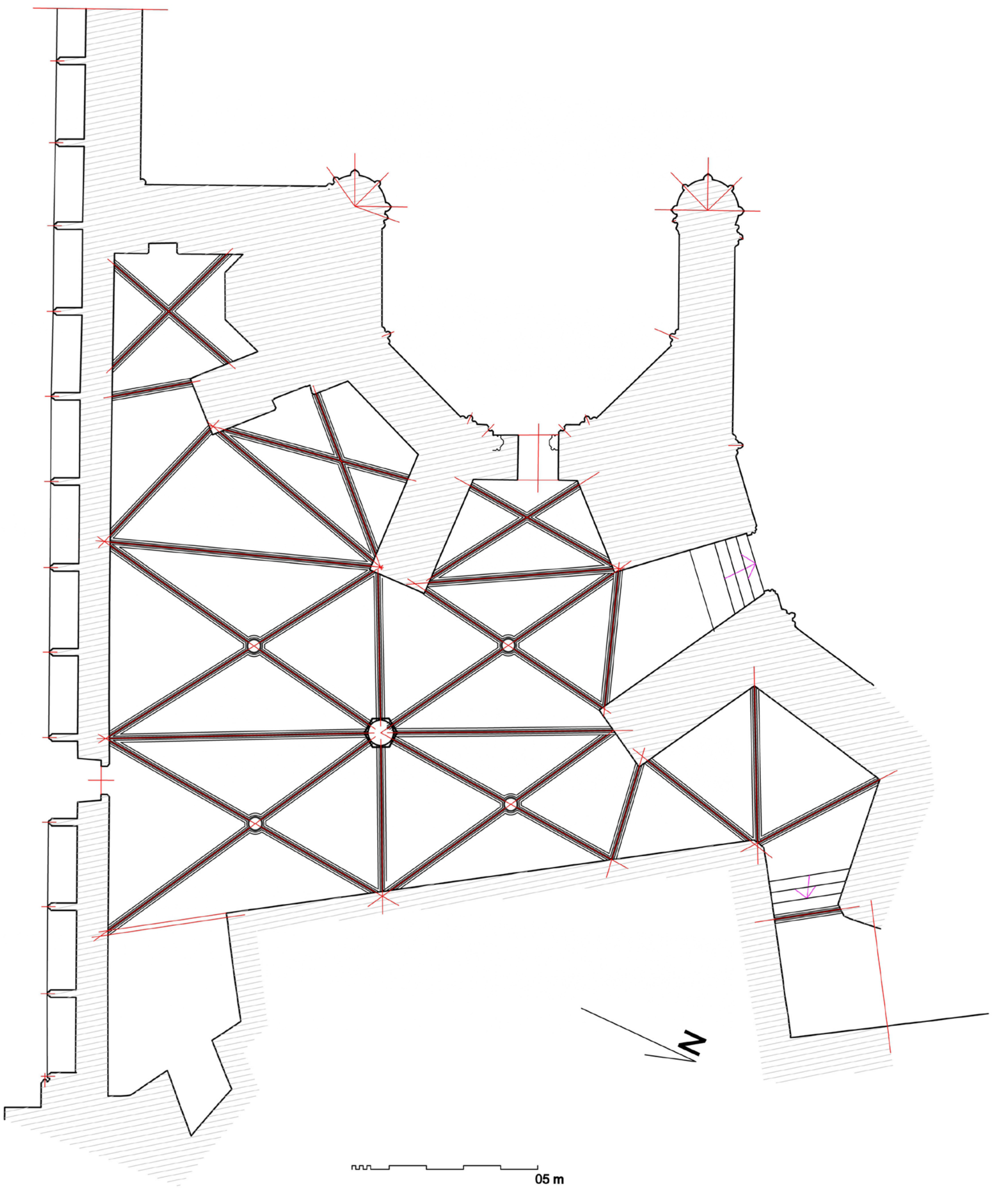

Fig. 11. Guillem Sagrera. Final plan of the three-vault solution and conventional four-vault layout, Chapter House, Cathedral of Saint Jean Baptiste, Perpignan (graphic elaboration by the authors).

Fig. 12. Guillem Sagrera. Chapter House, Cathedral of Saint Jean Baptiste, Perpignan (photograph by the authors).

to us stylistic concessions, but are in fact structural and constructive: "The design, control and construction of the vault are carried out by means of only three elements: the plan of the ribs, the elevation of each rib and its section" [Senent Domínguez et al. 2012, p. 79].

When observing the vault, the first question that arises is why he made these lines of three vaults, instead of covering the space with four vaults from the central column (fig. 11), which would be the solution used when a double ambulatory appears, with the difference that in these cases the ribs follow the radial direction. In Perpignan, being a triangular portion with two clear directions, he discarded the idea of radial lines. In our opinion, the reason is twofold. On the one hand, the solution executed is more efficient from a structural point of view, since it resolves the covering of the same space with three vaults instead of four. On the other hand, the motif is also aesthetic, it achieves an organic effect on the spine, with the starts of the ribs at different heights, thanks to the size of the arches.

The corbel of the Chapterhouse

Llama la atención en este espacio la única ménsula exis-
The only existing corbel in this space is striking, appearing on the edge of one of the buttresses (fig. 12). A floral corbel that is the only decoration of the ensemble in addition to the three keystones. "Its origin is not clear, but it seems strange that only one appears in the whole ensemble" [Senent Domínguez et al. 2012, p. 77] looks at this corbel and concludes that it is not an error [Senent Domínguez et al. 2012, p. 80], hypothesizing that if it were not present, this corbel would have forced the dismantling of three more rows of the buttress, about 77 cm, to embed this rib, due to the *tas-de-charge* construction system [10], since this corbel receives the longest rib, whose elevation is determined by the height of the keystone. He also believes that the pillar is not located in the centre between the buttress and the wall, but is slightly offset towards the wall [Senent Domínguez et al. 2012, p. 80]. Using the digital model it can be seen that the pillar is indeed slightly displaced, but this displacement is 24 mm, which we consider negligible in a length covered by the arch of 8,000 mm, so Sagrera's intention was to place that pillar in the centre of the space and he did so.

To avoid the corbel without having to dismantle the buttress, there are two possible solutions: one solution would have been to change the position of the pillar, to reduce that span, but this solution would contradict the idea of a central pillar, which seems clear in Sagrera, so it can clearly be ruled out. The second would be that the longest rib should not rest on the edge of the buttress, but on the buttress's vertical surface, thus reducing its length. But aesthetically it would not be such a refined solution, so it is also ruled out. On the other hand, placing the corbel to avoid dismantling three more rows of the buttress, up to a height of 1.84 m from the ground, while in the area on the left there is a buttress that is dismantled up to a height of 1.64 cm, does not seem definitive either.

Sagrera places the pillar in the centre enhancing the only symmetrical arches of the assembly, with a double deep edge [11], the vertical edge. As for these arches on the corbel, he could have done it to emphasise not only the idea of the corbel, but also the idea of the two symmetrical arches. What other meaning could it have than this edge protrudes 8 cm from the buttress, when the arch is only 2.5 cm longer than its symmetrical, where it is not emphasised in this way.

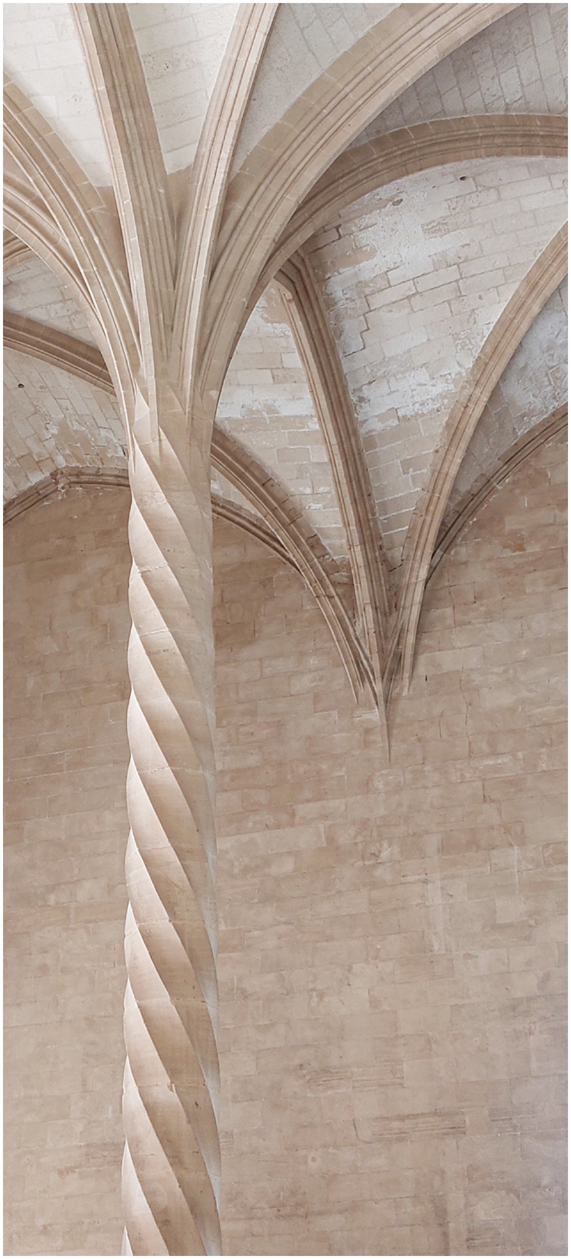

Fig. 13. Guillem Sagrera. Detail of the rib-to-wall junction, Lonja de los Mercaderes, Palma de Mallorca (photograph by the authors).

Fig. 14. Guillem Sagrera. Detail of the rib-to-wall junction, Sala dei Baroni, Castel Nuovo, Naples (graphic elaboration by the authors).

In our opinion, this corbel appears projected from the outset, it is not a mistake, nor a cost-driven revision, but indicates the desire to experiment structurally and aesthetically, where, from structural sincerity, we can place a corbel so as not to dismantle a buttress, when in the rest of the building it is not necessary to do so. This knowledge was applied in the Mallorca Maritime Exchange around 1426, so chronologically it must have been applied in the chapterhouse earlier than Alomar claims.

Conclusions

Studying Sagrera's work from a graphic point of view, data is provided on the result of the three-dimensional analysis, with respect to his least known period between 1400 and 1416, during which time he lived in Roussillon, with frequent trips to the North and the South. Parallels are established between his sculpture, with a clear influence from Burgundy, to suggest that he could have participated together with Vaulter in the construction of the Perpignan Maritime Exchange, and that this work could have facilitated his access as a master builder to the future Cathedral of Saint John the Baptist, as evidenced in the Girona consultation of 1416. This same sculptural influence was also architectural. It materialised in his first great architectural work, the chapterhouse of the future cathedral of Perpignan. The usual road between Perpignan and Dijon passes through Narbonne

and Avignon, in these places he probably knew the cloister of Narbonne Cathedral, where there are no corbels or the Palace of the Dukes of Dijon and the Popes of Avignon, where you can see examples where a central pillar also lacks a capital.
The claim that the chapterhouse of the Cathedral was built between 1433 and 1447 is refuted, indicating that it must have been at least before 1427. We base this conclusion on this sculptural influence, which has an equivalence in his architectural work, and which would mark a notable stylistic change, simplifying the lines and giving aesthetic importance to the structural elements. This learning process would be reflected in the chapterhouse of the Cathedral, which he would use to experiment with formal solutions. For this analysis of the room, a 3D model with millimetric precision was obtained and as a result of the use of this tool it was verified when, where and why the capitals and corbels disappear in Sagrera's architecture.
The consequence of this experimentation in the small room, almost residual from Perpignan Cathedral, would be reflected in his two most important later works: the Mallorca Maritime Exchange (fig. 13) and the Sala dei Baroni (fig. 14). In the first, "in order to achieve the desired interior space, Sagrera had to resolve some construction elements through unique solutions, which would not have been possible by using modulation alone" [Cifuentes Utrero 2015, p. 459]. In other words, Sagrera transgresses the module he learned in the chapterhouse of Perpignan. In the second case, the Sala dei Baroni in Castelnuovo in Naples, as Ricardo Filangieri points out: "A report signed in May 1458 clarifies that Sagrera –with his collaborators– was responsible for the construction of the great Hall" [Domenge 2007, p. 78].

Credits

This article is part of the research line of the GRAHyC research group, Historical and Contemporary Architectural Representation Group.

Notes

[1] Known as Rich Alamant, a Flemish master who had previously worked on Barcelona Cathedral [Teres 2011, p. 174].

[2] It may be that this sculptor is the same one known as John of Valenciennes, documented in Bruges between 1379 and 1386 in charge of the sculptural decoration of Bruges City Hall [Teres 2011, p. 174]. This master belongs to the circle of artists of the pre-Burgundian style, along with Sluter [Alomar 1970, p. 94].

[3] The contract, dated 11 March 1426, contains a contract price of 22,000 Mallorcan pounds and stipulates the form of payments, so that, in this commission, he was not only going to carry out the work of architect and sculptor, but also that of contractor and coordinator [Alomar 1970, p. 124].

[4] Everything seems to indicate that Rotlino or Raoul or Rotlli Vautier or Vaulter or Gaulter was a native of Normandy and had a brother who was also a master builder named Carli, who worked on the designs of Seville Cathedral and Lleida Cathedral.

[5] Girona Cathedral was initially designed with three naves, after the construction of the apses, a single nave was chosen. Ten master builders of the Crown of Aragon were consulted on the technical and stylistic feasibility. All endorsed the technical possibility, although only four supported it stylistically. Sagrera advocated the option of a single nave.

[6] Such as the construction of the three pointed arches, which are preserved today, belonging to a loggia in the Palace of the Courts of Perpignan made between 1424 and 1427.

[7] The Lonja (Exchange) is a cubic volume with two floors: the lower one, porticoed, opens onto carrer dels Mercaders and the Plaza de la Lonja. The façade to Mercaders, the first to be executed, has two ogival porticoes without ornamentation on the ground floor and two windows on the upper floor.

[8] There is a panel preserved in the Rigaud Museum, painted 1488, belonging to the altarpiece of the Trinity where a building can be seen that may be the Lonja del Mar (Maritime Exchange).

[9] These dates coincide with the appointment of Galceran Albert as bishop of Elna in 1430, after having been bishop of Mallorca (1426-1429), where he developed the cathedral with Sagrera as master builder [Alomar 1970, p. 106]. In Roussillon he promoted the renovation of Saint John the Baptist with new designs, in accordance with those proposed in Girona and adapted to the new functions of the building after the loss of the capital of Perpignan.

[10] The French term, '*Tas-de-charge*' (springing block), is applied to refer to the lower rows of ribs in a vault, which are arranged horizontally and receive the vertical load. They generally rise about one-third the height of the vault and, when projected forward, reduce the span to be vaulted.

[11] Sagrera only distinguishes three arches with double edges, the two symmetrical and the one from the access from the church, although the latter is narrower than the other two.

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Giotto and the Construction of Space. The *Stories of Saint Francis* in the Upper Basilica of Assisi

Stefano Bertocci, Roberta Ferretti

Abstract

Interest in the pictorial representation of architectural space has deep roots in classical and Roman antiquity and has developed as a form of decoration or as an integration of built architecture with virtual special constructions, continuing into the modern age. In the first half of the fourteenth century, a substantial evolution took place: painted architecture was emancipated from its traditional role as a mere backdrop, typical of the Byzantine tradition, to acquire volumetric and perspectival consistency, capable of actively interacting with the symbolic and narrative construction of the scene. This transformation can largely be attributed to Giotto, who reinterpreted the Roman figurative heritage in an original way, drawing from a vast repertoire of classical sources and integrating his pictorial compositions with architectural models of contemporary buildings. The cycle of the Stories of Saint Francis*, attributed to Giotto and his workshop and executed between the late thirteenth and early fourteenth centuries in the Upper Basilica of Assisi, represents the first fully realized example of this new approach. This study constitutes an initial reflection within a broader research project based on a high-accuracy digital survey of the decorated interior surfaces of the basilica. The pictorial cycle is thus examined not only as an ordering principle of real space but also as an opportunity to explore drawing as a tool for knowledge, analysis, and mediation between architectural conception and figurative narration.*

Keywords: integrated digital survey, Basilica of San Francesco in Assisi, documentation and interpretation of medieval frescoes, perspectiva naturalis.

Introduction

In the first half of the fourteenth century, a significant evolution occurred in the representation of space, with painting acquiring greater volumetric consistency. This renewal is primarily associated with Giotto, who redefined the pictorial language with a heightened sense of realism, adapting it to the sensibilities of his time. The cycle of the *Stories of Saint Francis* in the Upper Basilica of Assisi, executed between the late thirteenth and early fourteenth centuries, represents the most accomplished example of this innovative phase, revealing a conscious interaction between figures and space, founded on principles of structural coherence and verisimilitude. The construction of the Basilica of San Francesco in Assisi, articulated on two levels, was a complex process that unfolded over several decades.
The Upper Basilica (fig. 1) introduced a radical innovation within the architectural panorama of central Italy, assimilating the significant stylistic and structural developments then emerging in the transalpine regions. Gothic forms, reinterpreted through the lens of local building traditions, gave rise to an unprecedented architectural organism in which architecture, painting, and decoration –including the stained-glass windows executed by northern European workshops– were harmoniously integrated into a coherent, unified whole.
Giotto played a decisive role in this turning point, reworking the Tuscan and Roman figurative traditions with remarkable originality. Drawing from a vast repertoire of classical sources –such as bas-reliefs, wall paintings, coins, and mosaics– he

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integrated these references with elements derived from contemporary medieval architecture, creating a new synthesis between ancient models and the visual culture of his own time [Benelli, 2016]. Since antiquity, the pictorial representation of architectural space has been a recurring theme; however, it is between the late thirteenth and early fourteenth centuries that architecture definitively emancipated itself from its traditional role as a scenography, Byzantine-inspired backdrop, acquiring its own volumetric and perspectival autonomy [Benelli 2016].
It is by no means a novelty to approach great works of art with a critical eye, seeking new elements or original insights, and considering them not only from a historical-artistic or aesthetic perspective, but also as valuable sources for reconstructing the cultural dynamics of their time. The cycle of the *Stories of Saint Francis*, executed by Giotto and his workshop in the Upper Basilica of Assisi, stands as the most accomplished example of the ideas outlined above. The decorative scheme of the central nave –featuring the parallel narratives of the *Life of Saint Francis*, the *New Testament*, and the *Old Testament* [Romano 2017]– reflects a well-established pictorial tradition in central Italy. This tradition finds its most illustrious precedents in the mosaic decoration of the dome of the Baptistery of San Giovanni in Florence, in the Roman mosaics of Pietro Cavallini, and in the wall paintings of the Hermitage of San Benedetto at Subiaco.
In the fresco cycle executed by Giotto and his workshop, a new clarity emerges in the articulation of the painted architectural framework, which not only organizes and visually supports the scenes but also enhances the structural coherence with the Basilica's real spatial context. The analysis of the frescoes, conducted by our research group together with the architectural survey of the Basilica's interiors, reveals a marked integration between real and depicted structures. These painted elements emulate loggias, projections, and architectural members of considerable visual impact, thereby influencing the overall perception of the nave's lower wall zones.
Furthermore, the painted architectures –depicted as landscape or architectural settings within the twenty-eight scenes of the cycle– do not perform a passive role. Instead, they function as active narrative devices, contributing significantly to the construction and interpretation of the visual narrative.
The research project presented here proposes an innovative reading of the fresco cycle, focusing on the analysis of the depicted spaces and settings, and offering a new interpretation of the representations of interiors, architecture, and urban environments in light of the technical and scientific knowledge developed during the Middle Ages, grounded in classical tradition. These representations serve as a visual summary of the architectural innovations of their time and can be interpreted today as a true treatise on medieval architecture in images. In addition to explicit references to the constructive aspects of the depicted architectures, allusions to major building sites then active in central Italy can also be found, such as the façades of Orvieto Cathedral and

Fig. 1. Interior of the Upper Basilica of St. Francis, Assisi (fotos by Stefano Bertocci).

that of the Baptistery of Siena Cathedral. Within this context, drawing –understood both as the graphic operation of the fresco painter and as an analytical tool enabled by digital surveying– plays a central role in the critical understanding and interpretation of the work.
The study presented here thus constitutes an initial reflection within a broader research project based on the acquisition of a high-accuracy digital survey of the interior surfaces of the Upper Basilica of Assisi. The project aims to analyze the fresco cycle of the *Stories of Saint Francis* not only as an ordering principle of architectural space, but also as a key to understanding the epistemic and communicative value of drawing itself, as a mediator between design thinking and figurative narration.
The work under examination lends itself to a stratified interpretation articulated across multiple levels of architectural representation. The first level concerns the painted architectural framework that encloses the pictorial cycle, characterized by twisted columns and painted architraves that serve both as an organizing structure for the scenes and as a mediating element between the real architectural framework and the narrative fiction. The second level consists of the architectures and landscapes depicted within the individual scenes, which shape the figurative space by defining visual hierarchies and symbolic meanings.
Particularly significant in this regard is the fourth episode of the cycle, *The Prayer in San Damiano*, where, through the expedient of architectural ruin, the represented building is opened in an almost axonometric section that reveals its internal structure and constructive principles. This visual language anticipates the use of architectural section as both a technical and narrative instrument. From this perspective, the *Stories of saint Francis* cycle not only highlights the expressive potential of architectural structures as ordering principles of both real and pictorial space but also enables a deeper reflection on drawing as a vehicle of knowledge, a tool for critical analysis, and a bridge between design imagination and iconographic representation.

Methodology

The study of the fresco cycle of the *Stories of Saint Francis* in the Upper Basilica of Assisi was conducted using a consolidated, integrated research methodology that combined digital survey tools with graphic analysis techniques. The objective was to provide a comprehensive critical reading of the frescoed surfaces, the architectural context in which they are set, and the relationships between the two.
The data acquisition phase employed a combination of laser scanning and photogrammetric surveying to collect both metric and morphological data, as well as chromatic and material information. This synergy enabled the creation of a high-resolution three-dimensional model of the basilica's nave, serving not only as precise geometric documentation but also as a reference framework for calibrating the photogrammetric models of the painted surfaces. The high-definition photographic mapping produced highly accurate models of the frescoed surfaces, correctly oriented and scaled with respect to the architectural survey, thus ensuring the metric and spatial coherence of the entire system.
Following the digital survey campaign, to develop a reliable digital reconstruction of the decorative apparatus, the vectorization of both the pictorial decoration and its architectural context was undertaken [Parrinello, La Placa 2019], which was fundamental for the subsequent analytical phase (fig. 2).

Fig. 2. Example of the digital survey of the Upper Basilica of Assisi, obtained through laser scanning and integrated with photogrammetric data, focusing on one of the bays (graphic elaboration by Roberta Ferretti).

Fig. 3. Perspective with vanishing axis: at the top, an example from the excavations of Oplontis, Villa di Poppaea; at the bottom, a bay of the Upper Basilica of Assisi with the three panels of the false loggia with perspective interpretation (graphic elaboration by Roberta Ferretti).

Through the medium of drawing, it was possible to analyze the compositional criteria adopted by the artists, the geometric matrices underlying the spatial organization of the scenes, and the optical and perceptual devices employed to confer three-dimensionality and depth to the painted architecture. The entire frescoed surface was then examined according to a stratified logic, organizing the information into different interpretative layers that reveal the internal coherence and complexity of the figurative project. A first level concerns the definition of the decorative framework, a painted architectural setting that frames individual scenes. A second level includes the narrative scenes themselves, along with the landscape and figurative elements, articulated within the established frames and engaging in a dialogue with the real space of the basilica.
The critical analysis of the frescoes was conducted through an integrated approach that considers the multiple layers of meaning within the work. Particular attention was given to the iconography and figurative and architectural models of reference, the composition of pictorial space and the distribution of figures within the scenes, the methods of spatial representation, and the role of color in shaping form and defining volume.
This methodology –based on the integration of digital surveying, graphic restitution, and interpretative analysis– has enabled moving beyond mere documentation, achieving a deeper understanding of the technical and design structures underlying the fresco cycle. It reveals the work's nature as a narrative and spatial device fully integrated with the architecture itself.

Spatial Strategies in the Painting of the Basilica of San Francesco in Assisi

The analysis of the decorative apparatus of the Upper Basilica of Assisi requires, first and foremost, a careful examination of the architectural structure that frames the scenes of the fresco cycle, of the iconographic and formal models that guided its conception, and of the representational strategies adopted to construct a complex effect of spatial depth and coherence. The nave of the Basilica is divided into four bays covered by ribbed cross vaults, supported by clustered pillars that rhythmically articulate the vast surfaces of the lateral walls. The decoration is organized into three registers: the stories of the Old and New Testaments unfold in the two upper tiers, while in the lower one, the *Stories of saint Francis* are depicted beneath the ambulatory, on a high base projecting slightly from the wall of the nave. The lowest section is adorned with a painted curtain motif –like those found in the choir and transepts– which visually introduces the narrative sequence above. Framing the twenty-eight scenes is a sumptuous painted architecture: a monumental colonnade with twisted columns, surmounted by a richly decorated frieze, supports a coffered architrave, which in turn is topped by painted corbels that illusionistically sustain the upper frame, marking the upper boundary of the pictorial field. This refined formal invention –alternating the continuity of horizontal

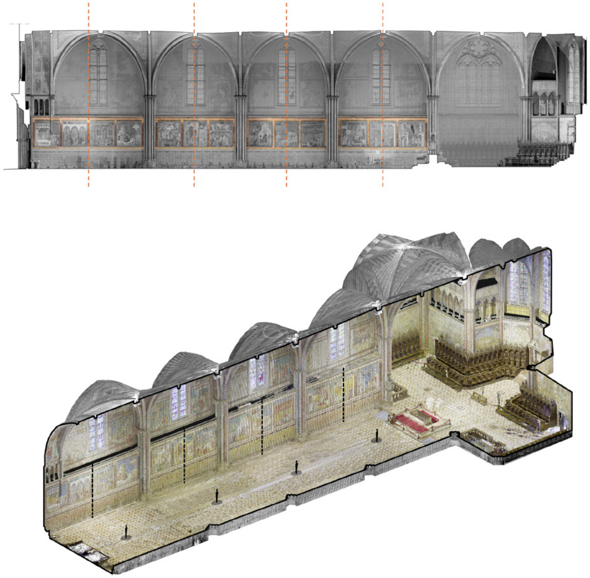
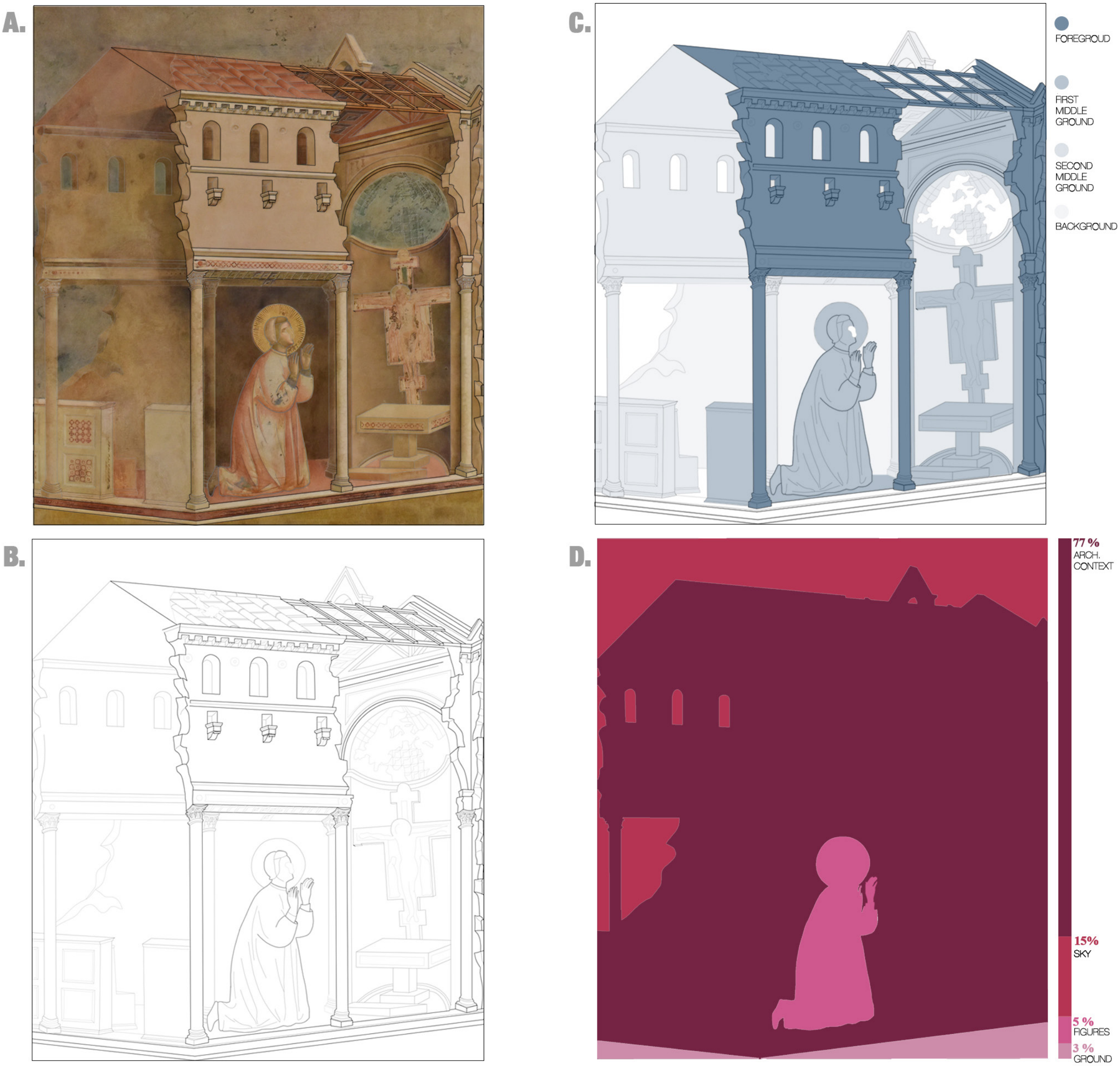


Fig. 4. At the top, processing of the longitudinal section of the Upper Basilica's interior from a point cloud, with interpretation of the organization of the Saint Francis fresco cycle; at the bottom, an axonometric section with a schematic representation of the observer's stopping points suggested by the position of the vanishing axes (graphic elaboration by Roberta Ferretti).

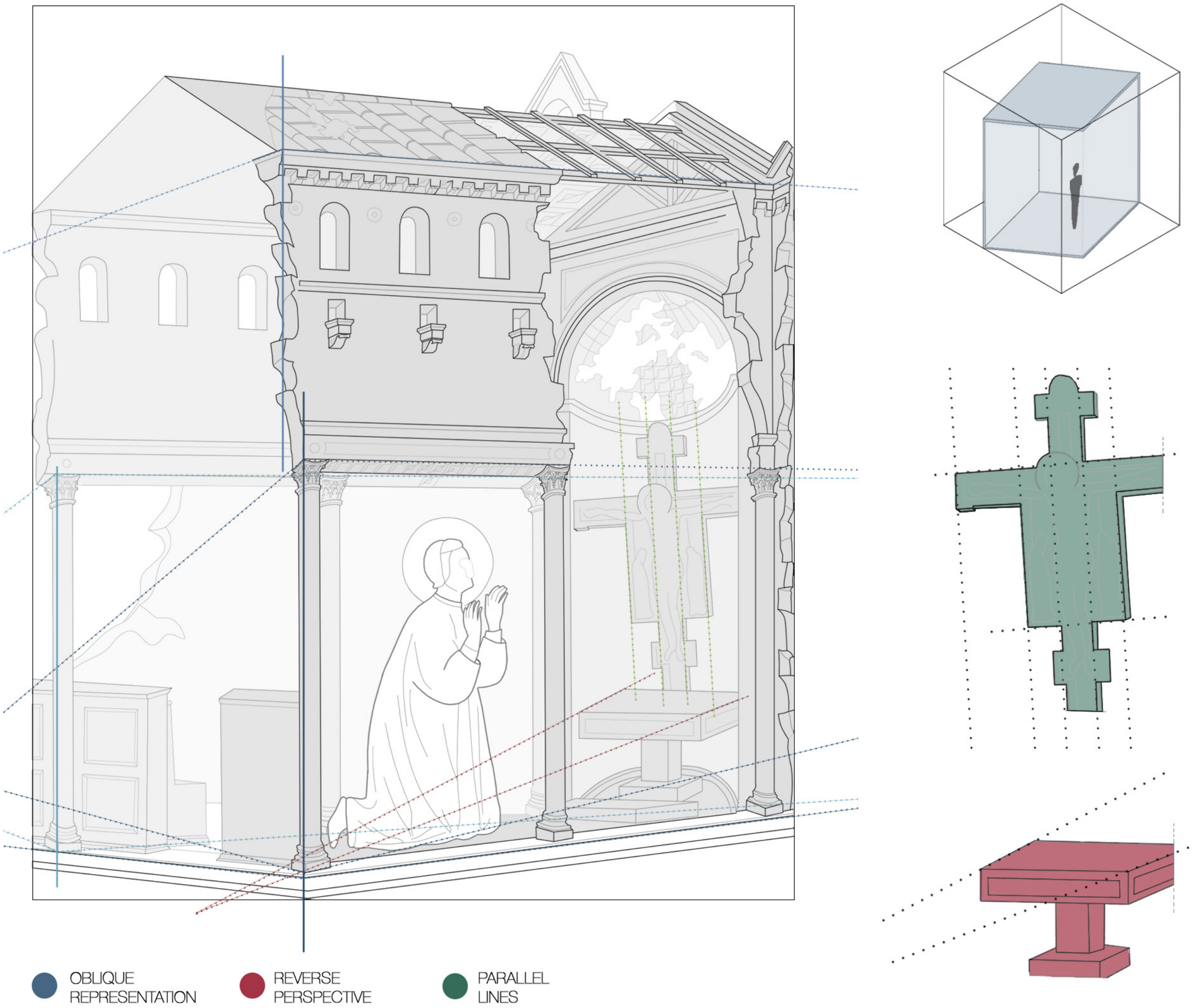
lines with the solemn vertical rhythm of the columns– constitutes the key to interpreting the overall structural conception of the decorative cycle [Gioseffi 1963].
A significant point of comparison in this regard is offered by the mosaic cycle of the dome of the Baptistery of San Giovanni in Florence, executed between 1225 and 1330. In that context, the structured use of architectural frameworks is particularly evident: the scenes are organized into distinct panels, delimited by columns that divide the space according to an orderly compositional logic, thereby imparting a regular, coherent rhythm to the visual narrative. Equally relevant examples can be found in monumental painting. Among these are the cycle of San Crisogono alla Cafferella and the twisted columns and perspectival corbels in the area attributed to Consolo in the decoration of the Sacro Speco at Subiaco [White 1971]. A particularly significant precedent that may have influenced Giotto's spatial organization of the nave paintings is the framing of the narrative scenes executed by Cimabue in the transept of the same Upper Basilica. From these, Giotto seems to have adopted the corbel model for his own compositional structure.
However, the illusionistic quality of Giotto's nave bays marks a decisive departure from these precedents. It is sufficient to compare the regular, oblique, and symmetrically parallel alignment of Cimabue's corbels –which converge at the midpoint in a form of reversed perspective– with the far more convincing sense of depth achieved by Giotto through the masterful use of one-point perspective. This use generates a 'spatial array' effect, articulated by the same corbels and the underlying coffered ceiling, resulting in a coherent and dynamic illusion of architectural space [Gioseffi 1963].
The use of painted architectural elements thus does not respond solely to compositional needs; it also introduces an illusionistic dimension that transforms the wall surface into a rhythmically organized space, suggesting an analogy with the real architectural articulation and creating a filter between the actual architecture and the individual scenes, which follow their own internal logic.
In this context, the division of the pictorial space and the perspectival management of the bays play a crucial role in defining the sense of depth and reorganizing the visual space within the nave. The artist does not passively accept the spatial segmentation created by the intercolumniation; this becomes evident in the analysis of the perspectival construction, which, rather than treating the nave as a single unified space, assigns each bay its own distinct focal point [Gioseffi 1963].
In each bay, all orthogonals relative to the bases and capitals of the columns, the coffered ceiling, and the projecting elements of the upper and lower frames converge in parallel perspective toward the central axis of that specific bay. The representational technique employed here is known as 'vanishing axis perspective' [White 1971] or 'herringbone perspective' [Panofsky 2013], typical of Roman painting (fig. 3), particularly the Second Pompeian Style, in which all orthogonal lines to the picture plane converge toward points placed along a single central axis within the composition.
This construction signals a profound shift from Cimabue's model, in which, as noted, the orthogonal lines were directed outward. The sense of realism is further reinforced by the artist's conception of the entire composition as if viewed from below, in accordance with the actual position of the observer.

Fig. 5. *Analysis of the Prayer at San Damiano episode: a. orthographic image of the scene; b. wireframe reconstruction; c. interpretation of the depth planes of the perspective box; d. quantitative assessment of the figurative and architectural components of the scene (graphic elaboration by Roberta Ferretti).*



To fully grasp the significance of treating each bay as an autonomous spatial unit, the viewer must not limit themselves to following the narrative or appreciating the formal play of an individual fresco; instead, they must perceive each bay both as an independent unit and as an integral part of a larger decorative system, interacting with adjacent and opposite bays across the open space [White 1971]. This mode of representation encourages the observer to pause at the center of each bay, thereby structuring the work's experience into distinct moments that simultaneously highlight the compositional autonomy of individual scenes and the narrative coherence of the entire decorative cycle (fig. 4).
A detailed examination of individual scenes reveals diverse strategies for spatial representation. Traditionally, art-historical scholarship [1] has focused primarily on the figurative component, while paying comparatively less attention to the landscape, urban, or architectural contexts that frame the action. For this reason, our investigation has specifically concentrated on the analysis of the background settings, understood as the scenography context in which the narrative unfolds, to explore their function and impact within the overall composition. From this perspective, the innovative significance of the so-called "Gothic realism" becomes particularly evident, especially in the careful contextualization of certain highly impactful scenes: among these are T*he Expulsion of the Devils from Arezzo*, *The Homage to the Simple Man*, in which the Temple of Minerva in Assisi's Piazza del Comune is depicted, *The Prayer at San Damiano*, *The Stigmata* episode set at La Verna, *The Verification of the Stigmata* within the Porziuncola, and *The Dream of Innocent III*, featuring the Lateran Basilica supported by the saint. In all these cases, the precise and objective rendering of the environments enhances the narrative's verisimilitude. It appears intended to encourage pilgrims to visit Franciscan sites, thereby offering an opportunity to symbolically relive those specific spiritual experiences [Bertocci 2024a].
The episode of *The Prayer at San Damiano* [2] is rendered by Giotto as a pictorial scene of extraordinary narrative intensity and formal innovation. The setting depicts a church in a state of ruin, with partially collapsed walls and roof, within which the saint is shown kneeling in prayer before a crucifix placed on a small altar, situated within a semicircular apse.
This scene assumes particular significance because, as Francesco Benelli [Benelli 2012] has emphasized, it marks the first instance –likely within the broader context of Italian painting– of representing a sacred building in a state of ruin. This iconographic device was subsequently adopted both by Giotto himself and by other artists, becoming a recurring expressive element.
Regarding the painted architecture, the depicted building does not constitute a faithful reproduction of the Church of San Damiano. In particular, the representation clearly shows a three-nave configuration, as indicated by the openings for roof beams in the lateral aisles. This iconographic choice diverges from the actual structure of the church, which at the time consisted of a single nave covered by a pointed barrel vault, with lateral chapels added only later, in accordance with standard practice in Franciscan architecture [Bertocci 2024b].
From a typological point of view, the building depicted in the fresco *The Prayer at San Damiano* accurately represents the ecclesiastical typology characteristic of the twelfth and thirteenth centuries. The artist demonstrates a precise understanding of the architectural features of the period, faithfully rendering formal and constructive elements that reflect real models of the Romanesque and early Gothic contexts. In particular, the structural solution, based on columns surmounted by an architrave –here enriched with Cosmatesque decoration– is consistent with the architectural practices of the time, reflecting a structural conception still rooted in the Romanesque tradition. This is further confirmed by the presence of three single-light windows providing illumination to the central nave. Such a configuration is found in several reference buildings, including the Roman Basilicas of Santa Maria Maggiore, San Lorenzo Fuori le Mura, and Santa Maria in Trastevere, which served as typological models for many churches constructed between the twelfth and thirteenth centuries, especially in central Italy.
Benelli further observes that, in this instance, the church is not depicted solely as a ruin but rather as a building arbitrarily disassembled for narrative purposes. The ruined elements are strategically selected to make the other subjects in the scene, in particular the human figure and the crucifix, visible. The intact portions of the building nonetheless contribute to maintaining the verisimilitude of its structural stability. Particularly significant is the treatment of the roof, generally the first architectural element to collapse and thus the quintessential symbol of ruin, which here is represented as partially intact. At the same time, the other half reveals the wooden truss structure. This iconographic solution, rather than documenting an actual state of decay, anticipates the modern principle of axonometric cutaway

Fig. 6. Analysis of the methods used to represent pictorial space. Highlighted: the overall spatial scheme, a detail of the cross depicted with parallel lines, and the altar represented using reverse perspective (graphic elaboration by Roberta Ferretti).



representation with detailed exposure of the roof structure and provides essential information about contemporary construction practices. Continuing the analysis, four distinct planes of depth can be identified within the pictorial scene (fig. 5c): the first, third, and fourth planes comprise the walls delimiting the three naves of the church, while the figure of the saint in prayer, the altar, and the crucifix occupy the second plane. Another particularly significant analytical approach explored in this context involves the quantitative assessment of the frescoed surfaces (fig. 5d), subdivided into figures, background, ground, and architectural context. This numerical data allows for a reevaluation of the artist's investment in the overall rendering of the figuration and underscores the scenic context's increased prominence within the pictorial composition.

For the building that occupies nearly the entire surface of the scene, the artist adopts a composition corresponding to the typology of the 'oblique representation' [3]. The structure is arranged diagonally relative to the picture plane, with an angle facing the viewer frontally, simultaneously revealing two principal sides in rapid perspective recession [White 1971].

This configuration accentuates spatial depth and endows the scene with greater plasticity, marking a significant departure from the frontality characteristic of the Byzantine tradition. The structure, depicted in a state of ruin through calibrated compositional cuts and perspectival glimpses, does not merely facilitate the legibility of the scene but reflects an advanced level of reflection on the construction of pictorial space. JohnWhite [White 1971] interprets this choice as the onset of a new phase in the history of empirical perspective, indicative of a growing interest in direct observation and a more naturalistic rendering of visual experience.

The predominant structural element in this representation is the building's corner vertical, which functions as the organizing axis of the composition and as a spatial reference point. As Decio Gioseffi [Gioseffi 1963] observes, the scene constitutes a unique instance in Assisi, being the only 'spatial box' represented in oblique perspective; a solution that, although common in depictions of objects or structural masses conceived as blocks, is unusual when applied to an exterior-interior architectural environment designed

Fig. 7. Photograph of the half-column interested by the painted false architectural frame: at the top, seen from outside the privileged viewpoint; at the bottom, seen from the privileged viewpoint (fotos by Stefano Bertocci).

as a spatial container. This visual approach seems to reflect, albeit intuitively, the principles of the ancient optic-geometric tradition as formulated by Vitruvius in the context of architectural representation [4].
Supporting the coexistence of elements from previous traditions with formal innovations in representation, the scene employs 'reverse perspective' [Florenskij 1990] to depict the altar. In this instance, parallel lines that lie outside the picture plane and would typically converge toward the horizon instead diverge. This technique, typical of Byzantine and medieval traditions, does not respond to mimetic concerns but reflects a symbolic conception of space, reserved for the depiction of elements connected to a transcendent dimension, thereby emphasizing their intangibility and sacredness. In contrast, the crucifix is rendered through a system of parallel lines, a form of axonometry employed throughout the cycle for inclined objects. The coexistence within the scene of an empirically oriented representation for the building and a symbolic representation for the altar reveals the complexity of Giotto's pictorial language, suspended between the observation of the sensible world and the aspiration toward the transcendent (fig. 6).

Conclusions

It has been observed that Giotto, particularly during his stay in Rome, may have assimilated optical theories derived from both philosophical and scientific thought, inaugurating a new conception of represented space [De Rosa et al. 2000]. In the Middle Ages, optics –still primarily based on the theories of Euclid and Ptolemy– was reworked by Islamic and Latin scholars according to a geometric model of vision grounded in the rectilinear propagation of light. For Euclid, the eye represents the apex of a visual pyramid, whose rays extend toward the object being observed; the apparent size of objects depends on the angle of vision and is inversely proportional to the distance from the observer. With Robert Grosseteste and Roger Bacon, light acquired a universal and mathematical significance: it propagates according to lines and geometric figures, and its effects are measurable. Bacon formulated the principle that the intensity of visual perception is realized along a straight line,

Fig. 8. Detail view of the decoration on the sub-arch extending over the circular buttress. Chapel of the Magdalene, Lower Basilica (fotos by Stefano Bertocci).

consolidating the idea of a space governed by proportional laws [Carlevaris 2024]. The treatises of John Peckham and Witelo, available in various Franciscan libraries in central Italy, solidified the concept of *perspectiva naturalis*, which interprets vision as a measurable physical phenomenon [5]. The analysis of the Assisi fresco cycle demonstrates that, beyond the narrative scenes themselves, even minor details contribute to integrating the decorative apparatus with the basilica's architectural structure. These observations appear to corroborate the hypothesis that the fundamental geometric principles underlying Giotto's compositions –the rectilinearity of light propagation, the concept of the visual pyramid, the proportionality of object sizes relative to the observer's distance, and the practical geometry of abacus schools– are essential elements of the new pictorial culture. These principles enabled the construction of a coherent space that serves the narrative of saint Francis's life. Giotto thus developed a novel approach to representing reality, grounded in optical and geometric relationships that actively engage the medieval viewer –pilgrim or devotee– in the dialogue between the Gothic environment and religious content.

Particular attention is warranted for the first bay adjacent to the entrance, where the artist does not adhere to the actual architectural partition between the narrow barrel-vaulted pseudo-narthex and the first groin-vaulted bay, instead unifying the two spaces pictorially into a single environment perceived by the visitor as central and intimate. In this space, scenes are arranged four per side, unlike the tripartite groups in the other bays. The colonnade's perspective reflects this organization, with a central twisted column occupying the middle of the fictive portico rather than leaving the central bay empty, as in the others. Giotto's perspectival performance engages not only flat surfaces but also three-dimensional architectural elements, such as the semi-column separating the two bays: here, the painted architectural frame extends across the semicylindrical surface emerging from the wall, executed to appear straight to an observer standing at the center of the bay (fig. 7), while its lower portion seems to be rendered as the sky of the scene below. This anticipates anamorphic effects that would be widely developed from the Late Renaissance to the Baroque [Aterini 2012]. In the Lower Basilica, restructured and redecorated in the early fourteenth century, further examples of such techniques can be observed, aimed at 'correcting' spatial perception – for instance, in the intrados decorations of the passageways connecting to the Maddalena Chapel (fig. 8). Specifically, the passage leading to the right arm of the transept features a complex decorative band on the intrados, which continues anaphorically deformed over the base of the large cylindrical buttress, offering the observer positioned on the altar side a continuous visual alignment of the arch. Giotto's attention to the overall effect of the work, as well as its relationship with the enclosing architecture, is also evident in the impressive decoration of the transept vaults, where the theme of the apotheosis of saint Francis unfolds, as well as in minute details such as the painted bench on the southern transept wall, which appears to emerge from the surface of the wall surface, covered with soft fabric, thereby invading the real space in an illusionistic manner. Such effects confirm what Giovanni Boccaccio, in a *novella* from the Decameron, attributes to one of his characters: "Giotto was so excellent with that […] he, with his style and pen and pencil, would depict its like on such wise that it shewed not as its like, but did often err in regard thereof, mistaking for real that which was painted" [Boccaccio 1930, p. 74].

Credits

Stefano Bertocci authored paragraphs *Introduction* ancd *Conclusions*; Roberta Ferretti authored paragraphs *Methodology* and *Spatial Strategies in the Painting of the Basilica of San Francesco in Assisi*. We wish to thank the friars and the technical office of the Sacro Convento of Assisi for their kind assistance.

Notes

[1] Vasari, in his *Vite*, reports that Giotto was summoned by Giovanni di Minio da Morrovalle, who served as general of the order from 1296 to 1304; however, the traditional attribution of the fresco cycle to Giotto had already been questioned at the beginning of the twentieth century. More recent studies, conducted following the 1997 restoration of the Basilica of Assisi, have reopened the issue of attribution [Fry 2008]. For this study, the individual hand responsible for executing the frescoes is not considered a significant factor; accordingly, throughout the discussion, reference will

be made to the author or authors of the work as "Giotto and his workshop".

[2] Taken from the second chapter of the Legenda Maior of Saint Francis, this episode marks a pivotal moment in the saint's biography: his spiritual conversion. According to tradition, the miraculous encounter with the crucifix occurred in the small church of San Damiano in Assisi.

[3] This type of representation has also been termed a 'corner view' (visione d'angolo) by Erwin Panofsky [Panofsky 2013].

[4] As Migliari and Fasolo [Migliari, Fasolo 2022] observe, Vitruvius' distinction between *ichnographia*, *orthographia*, and *scaenographia* reflects an articulation of architectural drawing based on different perceptual modes. Specifically, *ichnographia* describes the plan layout of a work, *orthographia* conveys its frontal elevation. At the same time, *scaenographia* appears to allude to a three-dimensional representation without a vanishing point, akin to what is today referred to as axonometry.

[5] In the Renaissance, one witnesses a shift from perspectiva naturalis –an inheritance from the medieval tradition, grounded in the study of direct and reflected vision– to perspectiva artificialis. While perspectiva naturalis investigates the mechanisms governing the formation of diminished images of objects, perspectiva artificialis emerges as the discipline concerned with their representation. For a detailed discussion of this distinction, see Luigi Vagnetti *De naturali et artificiali perspectiva* [Vagnetti 1979].

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Sketching Structural Lightness: Frei Otto and the Treehouses (1959-1987)

Virginia De Jorge Huertas

Abstract

Frei Otto's treehouse projects offer his vision through their detailed drawings and unbuilt architecture's structure hybrids. These works echo the ecological and anatomical analogies proposed by Philip Steadman, underscoring the deep connection between the built environment and natural systems. The concept of the 'treehouse' or Baumhäuser, and its intrinsic relationship with architecture and nature, was a consistent theme in Otto's work from 1959 to 1989. The treehouse is a timeless architectural idea, found across cultures and centuries from Papua New Guinea to modern designs by Baumraum studio. These structures blend structural design, nature, and spatial adaptability. The objective of this research focus in Otto's 'treehouse' concept through four key case studies from New York to Berlin. It begins by examining interviews, drawings and literature on his philosophy, tracing the concept's evolution from early unbuilt proposals to the Ökohaus in Tiergarten. This project, the most comprehensive built expression of these principles, was studied via fieldwork and drawing analysis to understand its materialization. Otto's earlier works –including watercolours, sketches, and experimental models– demonstrate his interest in architecture rooted in the genius loci and a holistic ecological vision. His treehouse projects exemplify a synthesis of form, construction, and environmental awareness, an approach that remains pertinent to contemporary architectural discourse.

Keywords: Frei Otto, treehouse, ecological architecture, Ökohaus, *architectural drawings.*

Introduction: drawing architecture and ecology, a symbiotic evolution

The complex relationship between architecture and nature, and the broader dialogue concerning ecology and the environment, has been a consistent thread in both theoretical research and applied projects. This fruitful discourse spans decades, encompassing pivotal works from Reyner Banham's *Four ecologies* philosophy [Banham 1971] and Murray Bookchin's *For an ecological society* [Bookchin 1978], to Philip Steadman's classification of architecture and nature [Steadman 1982] or Juhani Pallasmaa's research and exhibition in Helsinki published under *Animal Architecture* [Pallasmaa 2020]. More recent contributions include Kenneth Frampton's *Seven points for the new millennium* [Frampton 2003], Eduardo Prieto's *Historia medioambiental de la arquitectura* [Prieto 2019], Philippe Rahm with his *Natural history of architecture* [Rahm 2020] or Neri Oxman's *Biomorphism* and *Material ecology* [Antonelli 2020].

Steadman's 1982 framework provides a valuable lens, classifying this multifaceted dialogue into five key analogies: organic, classificatory, anatomical, ecological, and Darwinian. This research specifically focuses on the case of treehouses and the architecture of Frei Otto, emphasizing its strong ties to ecological and anatomical analogies. Otto's approach is characterized by two distinct yet interconnected 'ways of thinking'. The first, often termed 'thinking diagrammatically', involves his detailed study of

organic forms and their inherent relationship to climate. The second, 'thinking by modelling', centers on his exploration of ultra-lightweight structures, drawing inspiration from the skeletal forms of prototypes developed at his Institut für Leichte Flächentragwerke (IL). Both models are fundamental to his conceptualization of treehouses, linking a profound respect for trees with the innovative idea of their structure resembling an inverted catenary. On this basis, the treehouse operates as a model for an ecological architecture of adaptability.
Frei Otto's advanced treehouse projects, discover for his sketches, diagrams and models, draw from a valuable history of examples and design strategies. The concept of arboreal dwellings has European roots stretching back to the Roman Empire in the province of Lycia and monasteries during the Middle Ages [Aikman 1988]. Beyond Europe, precedents like the Airy dwellings nestled among the Itá palm trees in the Orinoco Delta and Kenya's renowned Treetops Hotel also stand out. A particularly significant historical reference is the Parco Mediceo in Pratolino, near Florence, established in the mid-19th century by the de' Medici ducal family (fig. 1). This project showcases a double spiral staircase winding around a tree, providing access to hanging gardens and platforms at various heights for social gatherings. An engraving by Stefano della Balla vividly illustrates this structure, depicting a wide-trunked tree with two staircases coiling around its expansive central trunk. This imagery is further contextualized by the 1599 lunetta by Giusto Utens of 1599, offering a glimpse into the historical design. The historical lineage of treehouses, and their function as elevated social spaces, provides vivid context for understanding Frei Otto's projects. Anthony Aikman's work developed on treehouses [Aikman 1988], for instance, recreates the intricate spiral staircases of the Fontana della Rovere, an example seemingly in dialogue with other early references like those at Cobham Hall and nearby Plessy. These structures illustrate a shift from utopian ideals to practical, elevated platforms for gathering, playing, eating, and debating, offering families a retreat from urban life, particularly near Paris. The 17th-century diarist John Evelyn, a keen observer of gardens and woodlands, was so captivated by Lord Cobham's treehouse that it inspired his treatise *Silva* and led him to construct his own treehouse in 1646. Beyond

Fig. 1. Medicean tree house in Pratolino and the Tree house at Cobham Hall (redrawing by the author after Anthony Aikman) [Aikman 1988, p. 44].

European examples, diverse global precedents exist, such as the dwellings of the Koiari people in Papua New Guinea, the temporary shelters crafted from felled trees by settlers in Klallam lands in Washington, and the bamboo structures built by residents around a central tree near Aldeia Marakanã [Beaumont 2021]. Contemporaries of Frei Otto also explored the symbiotic relationship between trees and architecture. Notable examples include 1951 Glass house by Lina Bo Bardi, 1962 Venezia Pavilion by Sverre Fehn, and the Smithsons' work, exemplified by the tree integrated into the Wayland Young Pavilion in 1959 [Fernández, Jiménez 2020]. These diverse projects highlight a shared fascination with integrating nature and built environments, a theme central to Otto's own architectural philosophy. This paper analyses Otto's unbuilt and built treehouse projects, exploring their potential to redefine a type of collective housing through the lens of the human ecology approach [Boughey 1973]. The paper is structured as follows: behind an introduction that establishes the historical background and context of treehouses, it details the methodology used in this research. Next, it introduces a part of the pivotal work done at the IL Institute and delves into the symbiosis between architecture and biology. The core of the paper then focuses on an in-depth analysis of Frei Otto's treehouse case studies, concluding with the findings and insights derived from the research.

Methodology

Fieldwork, handmade drawings and interviews

This research employs a qualitative and graphic-based methodology [De Jorge-Huertas 2019a], primarily centred on a detailed analysis of specific case studies (fig. 2). This first phase of the research begins by examining diagrams and interviews with Frei Otto himself [AA. VV. 1994; Lendt 2011; Escher, Förster 2012], providing invaluable insights into his foundational thinking. This phase is complemented by second one, a comprehensive review of existing literature, specifically focusing on the broader concept of treehouses [Aikman 1988; Martinez 2015; Nugraha 2023], Otto's own philosophical framework of *Occupying and Connecting* [Otto 2009], and the overarching principle of lightness as it permeates his architectural work.

The third phase involves a selection and analysis of all type of drawings (diagrams, sketches, watercolours, etc.), of both built and unbuilt treehouse case studies by Frei Otto, from 1959 to 1989. This comparative approach allows for a nuanced understanding of how the treehouse concept evolved and ultimately materialized, particularly in the context of the Ökohaus in Berlin. As the only constructed example among the studied projects, this casestudy became the subject of intensive fieldwork. This included on-site visits to directly observe its design and integration, conceptual diagrams, handmade sketches, digital redrawing and interpretation of the architecture along with interviews with its inhabitants to gather firsthand accounts of living within Otto's vision.

The four specific Otto treehouse projects under study in this third phase are: the 1959 visionary, yet unbuilt project for New York; the collaborative design of "a funicular model of a tree-like structure" that emerged from a student workshop at Yale University in 1960 [Roland 1970, p. 123]; the theoretical case study at Askanischer Platz in Berlin; and finally, the 'tangible' Ökohaus in Berlin, completed in 1991. This comprehensive selection aims to provide a robust framework for tracing the conceptual and material trajectory of Frei Otto's enduring interest with the relationship of ecology, the tree-like concept together with branched structures, and lightweight architecture.

Frei Otto's research: dragonflies, lightness and future housing

Dragonflies as bio-indicators: Otto's lightweight structures

In his key work, *Occupying and Connecting: Thoughts on Territories and Spheres of Influence with Particular Reference to Human Settlement* [Otto 2009], Frei Otto structured with drawings and geometrical diagrams each section around a concept or case study directly tied to human habitat networks within their ecosystems. This approach underscored the inherent connection between habitat design, architectural ecology, and the exploration of non-permanent forms [Ciezadlo 2013]. A particularly compelling example of this is Otto's use of the dragonfly as a metaphor and as structural micro-scale research (fig. 3). Dragonflies hold significant ecological importance; they are remarkably sensitive indicators of shifts in the health of aquatic ecosystems. Their rapid response makes them invaluable bio-indicators, capable of signalling both current environmental well-being and predicting future changes. Furthermore, their role as efficient predators, especially of mosquitoes, contributes significantly to environmental balance.

Fig. 2. Diagram of tree house projects and influences related to the projects (elaboration by the author).

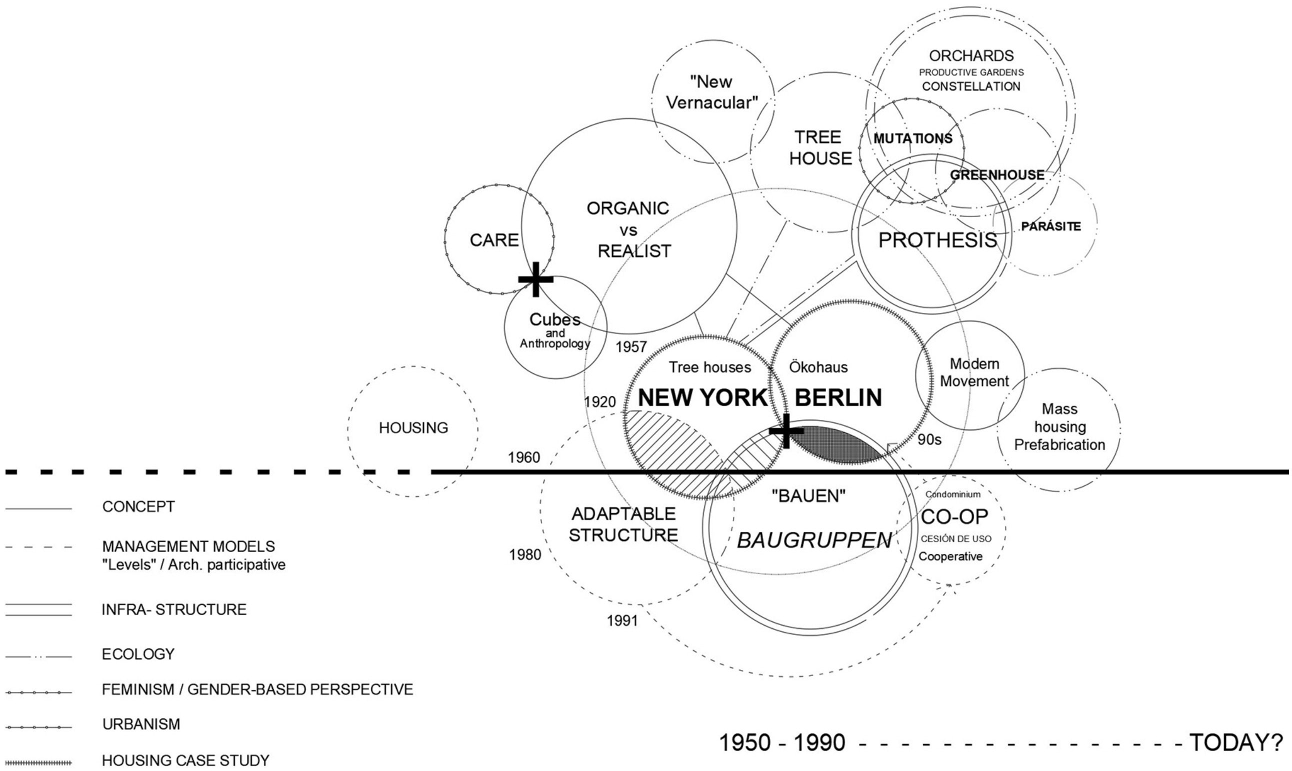
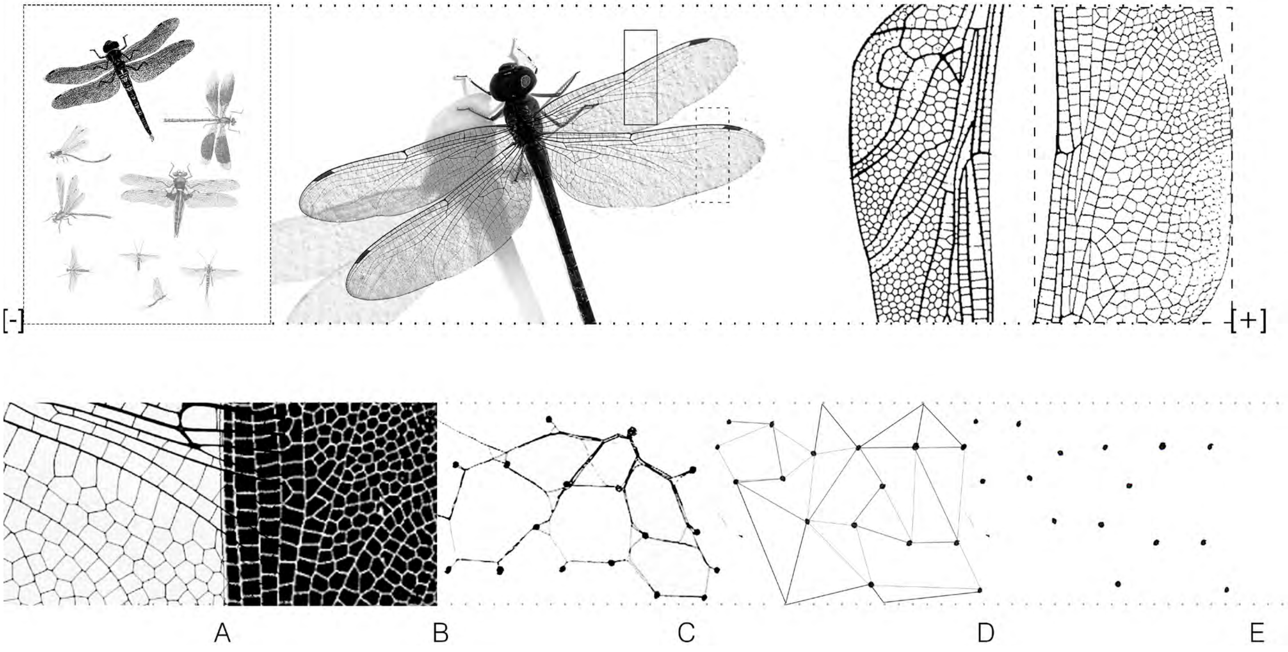


Fig. 3. Evolution and scalar structures (A-E) of the dragonfly and the wings geometry (A-B) towards patterns of occupation (D-E) (elaboration by the author).



Thinking by sketching: thinking diagrammatically and thinking by modelling

Dragonflies, which need stable oxygen levels and clean water, are also considered reliable bio-indicators of ecosystem health [Córdoba-Aguilar et al. 2023]. This ecological significance made them a key *leitmotif* in the analyses at Otto's institute for Structures and Conceptual Design (IL). This focus is a prime example of Otto's 'thinking diagrammatically' approach, a cornerstone of his extensive wok and unbuilt projects known [De Jorge-Huertas, De Jorge-Moreno 2024] and handed down to other generations by his drawings and pre-parametric diagrams. In his *Occupying and Connecting* [Otto 2009] illuminates, with handmade drawings and models, how various projects are crucial for understanding alternative methods of creating collective housing that prioritize lightness and customizability, contrasting sharply with traditional compact, serialized, and homogeneous designs. His experiments, theories, and prototypes reveal other ways to conceive collective housing from an 'ultra-light' perspective, as opposed to heavy and mass-produced solutions.

Otto's dragonfly structures are infra-light in time and ultra-light in matter, much like the soap bubbles extensively studied by the IL Institute. Both offer insights into developing experimental and alternative methods of eco-prefabrication and mass housing within Otto's broader research. The experimental essence of projects like the tree-house is further showcased in the IL's 'thinking by modelling' section, where Otto and his team experimented with ultra-thin membranes using physical models and line drawings. Dragonfly structures, light membranes and roofs, soap bubble assemblies and processes of occupation and connection [Otto, Nerdinger 2005; Otto 2009], as seen in the diagrams in (fig. 3), were central to Frei Otto's Atelier's studies from the 1950s to the 1970s. Their research explored flexible territories within self-constituting triangular grids, allowing for variable spatial sizes. Otto's drawings consistently feature three categories of light structures: small adaptable roofs, 'shield, umbrella, hood' (fig. 4) and numerous designs emphasizing lightness, a concept he intrinsically linked to saving material and, consequently, energy.

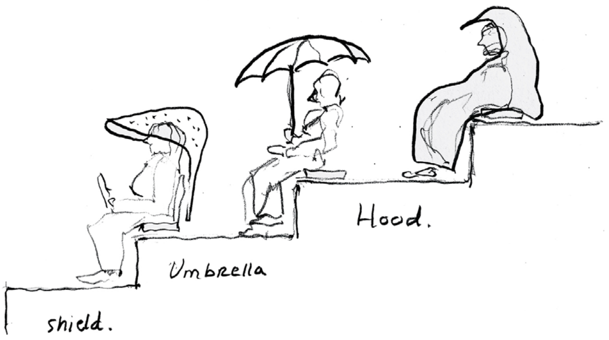


Fig. 4. Small adaptable roofs: shield, umbrella, hood and lightweight structures (elaboration by the author after Frei Otto) [Otto 2009].

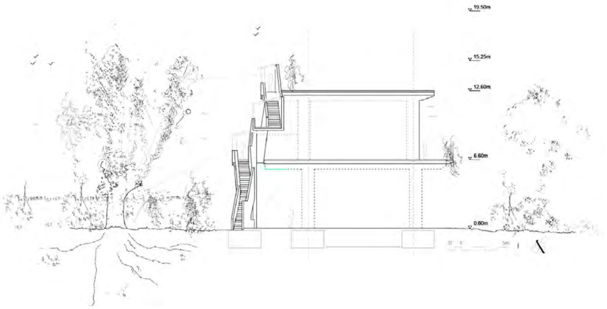
Ökohaus' organic genesis: biology, architecture and art

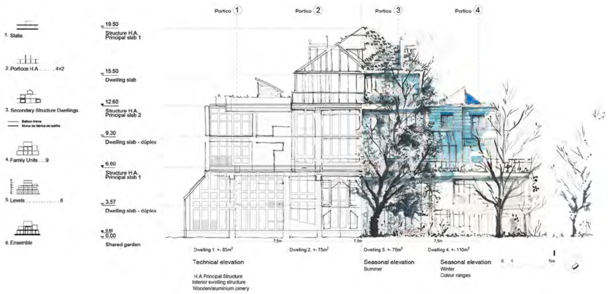
"Biology has become indispensable for architecture, but architecture has also become indispensable for biology" [Otto 1971b, p. 8]. The organic principles embodied in the Ökohaus likely stem from a confluence of influences: the interconnected diagrams analysing organic occupation patterns in Otto's research at his Institute, and the profound discussions between Otto and German anthropological biologist Johann-Gerhard Helmcke during the 1950s [Helmcke 1963]. Their conversations explored the intricate symbiosis between biology, architecture, and anthropology. Helmcke, a specialist in microorganisms, particularly skeletons of radiolarians and diatoms (a type of algae with silicified walls), introduced Otto to the concept of 'building form' in biology through the stereoscopic observation of these minute organisms. As Otto recounted in an interview [Escher 2012], Helmcke's insights came partly from his time as an unpaid tutor with professor Hans Poelzig, a close friend of Konrad Wachsmann's in Berlin. It was through a pair of students that Otto was introduced to Helmcke, who subsequently became a regular visitor to Otto's studio in Warmbronn and the Stuttgart department. Within this rich constellation of influences, Frei Otto also frequently cited Constantin Brancusi as the sculptor he most admired, recognizing Brancusi's exceptional mastery of plastic forms and craftsmanship [Glaesser 1972]. Otto systematically analyzed Brancusi's surfaces through a scientific process. These analytical processes were directly reflected in the seminars organized by the IL Institute for professionals and academics, where the focus was on the relationship between biological structures (animals and

Fig. 5. Stairs structure around the existing trees in the garden of the Ökohaus in Berlin (drawing and photos by the author).

Fig. 6. Exterior stairs and concrete skeleton structure section near the existing trees (drawing by the author).

Fig. 7. The Ökohaus elevation juxtaposes a structural line drawing with a phenomenological depiction (drawing by the author).





plants) and architectural design through drawings and models. These investigations, often captured in Otto's detailed diagrams, ultimately defined the highly spatial and organic character of the arboreal structures and frameworks that are hallmarks of his influential work.

A multidisciplinary manifesto for organic living. "A tree is not a tool for a living being, it is a living being itself" [Helmcke, Otto 1962, p. 856]. The Ökohaus in Berlin (fig. 5), co-directed by Frei Otto and its inhabitants, stands as a tangible manifestation of a multidisciplinary approach that bridges biology, sculpture, art, anthropology, and architecture. This concept finds its broader expression within the Baugruppe movement [De Jorge-Huertas 2019b] and is intimately connected to Otto's earlier, unbuilt experimental projects where the organic played a central role. These designs were infused with a utopian vision, which Otto articulated in his writings to improve future living conditions. This wasn't achieved through rigid, complete designs and drawings, but rather by establishing a foundational 'game board' with flexible guidelines and subtle rules, positioning architecture as a guiding framework rather than a prescriptive blueprint.

From microorganisms to mass housing. The Ökohaus, with its distinctive 'empty' structural section (fig. 6) and complete elevation (fig. 7), embodies the treehouse concept as an aggregation of diverse 'micro-organisms' within a single infrastructure. The Atelier Warmbronn and the IL research Institute meticulously analyzed the organic structures of various insects, such as the mathematically precise, unequal wings of anisoptera or zygoptera dragonflies. Their studies also extended to deformed meshes based on biological patterns, observing these not only in nature but also in the spatial arrangements of people around corners, analyzing their associative behaviors. While the Munich Pavilion remains a well-known example of a Voronian pattern application, the aim in the Baugruppe Ökohaus and its unbuilt treehouse predecessors was the abstraction and creation of a space entirely personalized by its inhabitants, where the structure and architecture recede into the background.

The Ökohaus's proximity to the Philharmonie and the Scharoun Library –a seminal figure in organic architecture– underscores the Warmbronn Atelier's deliberate move to create a built manifesto. This manifesto stands on the very edge of their experimental work with ultra-light structures. The Ökohaus's role as a 'drawing-built manifesto' and a political statement reflecting public engagement within the context of the IBA Berlin *(Internationale Bauausstellung Berlin*) also formed a crucial part of the research conducted by the Atelier and the IL Institute. This research focused on developing millimetric, almost imperceptible, living, and extremely slender envelopes for a new generation of building materials. For Frei Otto, these structures and materials were the driving force, enabling matter to lose thickness and mass while consistently prioritizing internal, adaptable, and mobile use.

Evolving conceptually through drawing

From Central Park in New York to Tiergarten in Berlin

Dreams, ecologies, and growth are core concepts underlying Frei Otto's projects and drawings centered on the 'tree house' or '*Baumhäuser*'. These include the New York project from the late 1950s with green roofs arranged like the branches of a growing tree (fig. 8), the 1960 Tree Structures Project (fig. 9), the unbuilt Berlin precedent at Askanischer Platz, and the, previously analyzed, 1989 Öko-haus in Tiergarten. Collectively, these works served as a laboratory for experimenting with the concept of the house, vertical density, and the multifaceted nature of the tree, as a metaphor and in its direct applicability.

The 'tree structure' of 1960 directly stemmed from Frei Otto's research into minimum surfaces and spatial relationships. Collaborating with students at Yale University, this experiment focused on multiplying compression elements to reduce individual buckling lengths, thereby decreasing both material use and structural thickness. Once the interconnected chords were stiffened and the model inverted, its organic configuration transformed into a tree-like structure [Glaesser 1972]. Parallel to this, a 1959

Fig. 8. Structure and construction process of the New York treehouse, 1958 (drawing by the author).

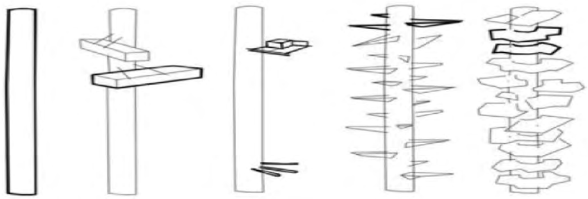
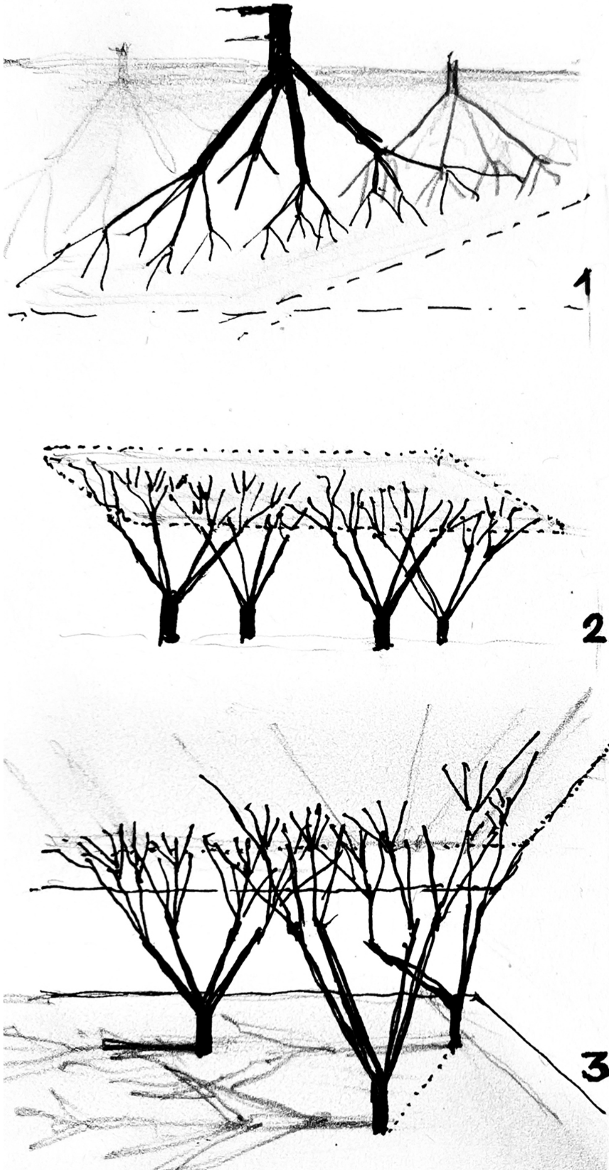
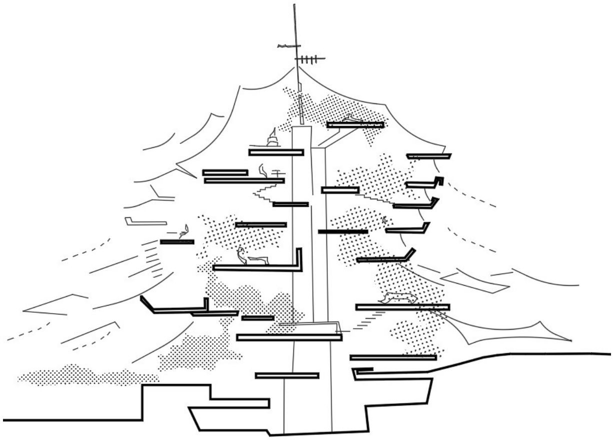


Fig. 9. Theoretical Tree-Structure Project, 1960. Funicular model (1). Once stiffened, the model is inverted (2-3) (drawing by the author).





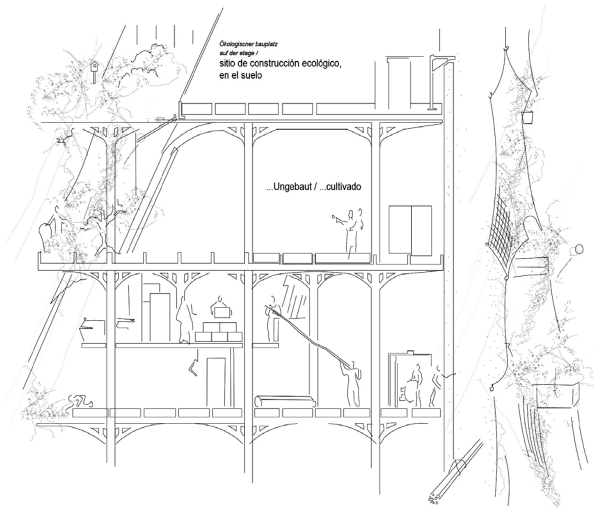


Fig. 10. Structure diagram of the Baumhäuser watercolour in 1980 (redrawing after Frei Otto by the author).

Fig. 11. Structure detail of the unbuilt treehouse project in New York, 1959-1960 (redrawing by the author after ARCH+ 57).

research project for a large-scale agricultural canopy, while serving as a greenhouse roof rather than housing roof, also thoughtfully integrated the growth of trees into its design. The genesis of Otto's treehouse ideas and drawings, surprisingly, came from a textile factory in Zehlendorf with a towering 220-meter chimney. As Otto recounted in an interview [Escher 2012], he envisioned drilling horizontal beams, 40 to 50 meters in diameter, into this chimney (fig. 10). This imaginative concept led to an adaptable skyscraper approach, allowing for cantilevered floors of varying sizes. Otto considered where such innovative apartment buildings could be realized, immediately thinking of New York. His familiarity with Central Park, gained through family in the city, provided the ideal backdrop for his conceptual treehouse towers [Escher, Otto 2012].

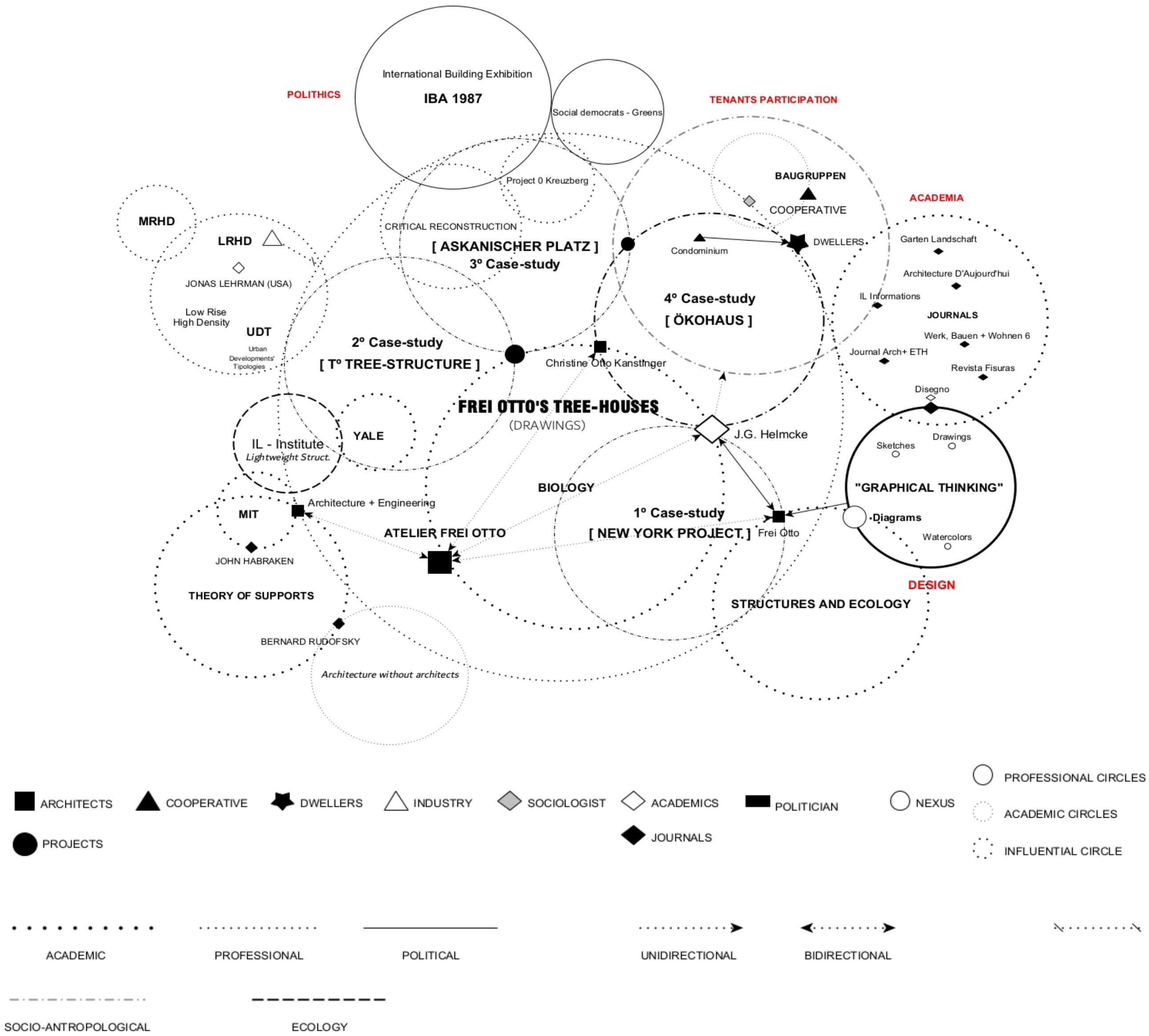
The most recent treehouse experiment, the Baugruppe-based Ökohaus in Berlin, represents a unique construction laboratory [Hamiduddin, Gallent 2016; Urban 2018]. Here, the builders are simultaneously the future tenants, collaborating directly with architectural firms and the construction team in a truly non-hierarchical structure. As we have seen before, this project stands as a powerful manifesto for architecture reimagined as a guide and tool to secure the fundamental right to housing. Frei Otto articulated his distinct views on housing through this innovative approach: "If housing units are taken to the third dimension, the hitherto unsurpassed degree of freedom of the detached single-family house must also be preserved" [Otto 1971a, p. 21].

Results: from tree house sketches to ecological cities

Ecological thinking, tree house conception and experimental housing

Frei Otto, in his correspondence with Giancarlo De Carlo [AA.VV. 1994], articulated a vision for housing units in the third dimension, conceptualizing a 'three-dimensional village' with utopic drawings [1]. This approach, consistently linked to an ethereal or mutable experimental dwelling, emphasized a degree of freedom rooted in ecological characteristics, while crucially preserving the privacy typically afforded by single-family homes. Otto further elaborated on these views in his 1980 lecture, *Natürlich Bauen*, delivered at the IL Institute in Stuttgart. The Ökohaus exemplifies this philosophy, offering an alternative, hybrid experiment between the single-family house and collective

Fig. 12. Network diagram of the research (elaboration by the author).



dwelling. It achieves this through a system of adaptable platforms that allow for mutable domesticity, a concept directly building upon Frei Otto's earlier proposals for New York. Building on these principles, the innovative architect articulated his core perspective regarding housing and its inherent need for adaptation: "What we have not yet had in houses is the adaptable construction, able to follow without delay all the modification of the wishes and needs of the occupant. Adaptable construction represents the total mastery of technique; it is very old and has been proposed. It is only cultivated in mud houses and in modern industrial construction. We know it in its different forms. First, we have the house, but also the large, anonymous, discrete structures, whose shape is not visible, which can grow or shrink, which multiply the area of the building site and which, according to needs and aspirations, can be extended with complete freedom of form inside and outside" [Otto 1971a, p. 21].
In 1959, Otto had already begun researching ecological housing for his New York tree house proposal. Domestic spaces, alongside courtyards, were integrated into branches or slabs, interspersed with raised gardens between dwellings. The design strategy featured a central, vertebral cylinder structure to which irregular floor slabs were anchored. This allowed for free floor plans and varying heights (within limits), where residences would coexist with their own gardens and orchards, as illustrated in the section in figure 11 (fig. 11). Frei Otto's unbuilt proposals for Skyscraper Trees, or three-dimensional garden cities as he termed them in 1958, represent parallel utopias. These concepts predate the Ökohaus and serve as antecedents to the Foundation for Architectural Research (SAR) Support Theory [Habraken 1961]. Both proposals share an initial design strategy centred on the treehouse concept, yet their scale varies significantly: one is a high-density, high-rise macro project for New York, while the other is a medium-to-low-density proposal for Berlin. Both were designed for competitions.
The design and drawing strategy from the New York project found a parallel in the initial 1981 proposal draw for the Ökohaus at Askanischer Platz in Kreuzberg. Here, the vision was to construct two skyscrapers of varying heights, featuring domestic hanging gardens every six meters. Within these intervals, each resident would insert their unique 'nest', a deliberate contrast to the standardized, homogeneous 'honeycomb' housing model. This treehouse project, a precursor to the built Ökohaus in Tiergarten, was a collaborative effort with Heinz Doster and Johannes Fritz in 1981. The concept centred on a 'three-dimensional garden city' [Archiv für Architektur und Ingenieurbau], reaching a total height of 60 meters and a width of approximately 35 meters. This prototype was designed to accommodate 50 one- or two-story dwellings, primarily powered by renewable energy sources, notably solar. In this early design, Frei Otto was already envisioning a lifestyle that diverged from the traditional single-family house. He sought to reconcile the individual's need for horizontal space and privacy within a domestic setting with the advantages of high-rise buildings. These pioneering ideas, mainly known thanks to the drawings and 'invisible' networks (fig. 12), directly paved the way for the *Baugruppe* Ökohaus, which would be constructed in Berlin a decade later.

Conclusions

The concept of the tree house, or 'Baumhäuser', and its profound link to architecture and nature were constants throughout Frei Otto's work. While the Ökohaus in Berlin stands as the most significant built example of this idea, his earlier studies –captured and known thanks to his diagrams, sketches, watercolours, and experimental models– reveal a long-standing interest in developing an architecture deeply connected to the *genius loci*, or spirit of place. Otto's vision for housing moved beyond traditional forms, imagining a 'three-dimensional village' where mutable dwellings provided freedom and ecological harmony while preserving individual privacy.
The treehouse is a timeless concept, with a history spanning centuries; from the dwellings of the Koiari people in Papua New Guinea to contemporary projects like the one by Baumraum studio in Osnabrück. Ultimately, Frei Otto's treehouse drawn projects are a powerful example of his deep interest in ecology, lightness and the environment. Also, on scientific communication through his IL Institute with the drawings, texts and models published, concepts that remain profoundly relevant in architecture today. These ideas resonate with current debates on participatory, adaptive and lightweight housing. This strength the contemporary relevance of these findings. Future research could be focus on other unbuild projects and his drawings, examining quantitatively the 'IL Informations' or deep on his watercolour-approach, sketches or diagrams.

Note

[1] For more detail on original sketches, see drawings online: <https://www.moma.org/artists/66414-frei-otto> (accessed 1 July 2025), <https://www.e-flux.com/architecture/housing/332652/apartment-buildings-for-new-york> (accessed 1 June 2025).

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Beyond the Limits of the Constrained View: Interactive Digital Spaces for the Perspective *Quadrature* of the Royal Palace of Portici

Alessandra Pagliano, Barbara Ansaldi

Abstract

Between the 17th and the 18th century, quadraturism established itself as a technical and conceptual device capable of altering the perception of the architectural space: by means of linear and aerial perspective –sometimes rigorous, at other times departing from geometrical principles to create deliberate artifices– the quadratura *creates the illusion of a depth that dematerializes the wall surface, expanding the space behind its physical boundaries. This results in alternatives and fictional spaces of unlimited depth, interacting with the real structure, enriching its spatiality to the point that it becomes impossible for it to maintain an independent and autonomous identity. Thus, a tension is established between what is real and what is represented through the use –for illusory purposes– of perspective drawing: this tension is what makes the Sala delle Guardie of the Royal Palace of Portici (Naples) an emblematic case of 'revealed structure' through drawing, the latter intended as an act of knowledge, interpretation and organization of visible space. By means of digital photogrammetric survey and perspective restitution of painted architectures, research intended to critically reinterpret the rules and derogations adopted by the artist-scenographer in designing his 'augmented' space in terms of spatial perception, offering a three-dimensional reconstruction of the painted architectures in order to allow their exploration from unrestricted viewpoints through Augmented Reality and Virtual Reality.*

Keywords: quadraturism, reverse perspective, Augmented Reality, royal Palace of Portici.

Introduction

Quadraturism is a style of pictorial decoration which emerged mainly during the 17th and the 18th century and is characterized by the perspective representation of painted architectures that merge with the actual space in an illusionistic way, simulating a spatial continuity between the two. The quality of the psychological and emotional experience of such spaces, 'enhanced' by the painted perspectives, lies in the recognition and conscious enjoyment of their illusory value: similarly to what happens when observing a theatrical scene, the viewer is more deeply engaged in the experience of illusory spaces right when the artistic value of the representation is appreciated through an understanding of the geometric complexity of the projective processes that generated it. It was no coincidence that Charles of Bourbon commissioned stage designer Vincenzo Re to fresco the most representative spaces of the Royal Palace of Portici, where he applied his theatrical experience to the decoration of the Atrium, the Scalone Reale, the antechamber on the first floor, and the Sala delle Guardie. The purpose of the *quadratura* was not to simply decorate the plastered surfaces, but rather to give greater grandeur to the spaces, whose dimensions appeared inadequate to the rank of a royal palace. Re, in collaboration with the figure painter Crescenzo Gamba, executed the architectural perspectives of the Sala delle Guardie and of the First and Second Antechambers between 1744 and 1746 [Visone 2019, p. 153]. He resorted to the representation of scenic

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perspectives of false Baroque architectures which, breaking through the walls, would give the illusory sensation of the presence of other adjoining spaces. In compensating for the lack of real architectural structures, he staged the illusion of wide-ranging spaces, opening upwards toward the vision of allegorical representations. The research therefore offers a traditional interpretation of the geometric processes employed by Re and Gamba in creating the perspective *quadratura* of the Sala delle Guardie. It then aims to create a digital product for an interactive and conscious fruition of the painted illusory perspective spaces, contributing to a deeper understanding of the design mechanisms that give meaning to both the real and imagined architectural space.

Architecture as a frame for painted spaces: quadraturism and space beyond physical boundaries

At the heart of Baroque and late-Baroque artistic production, quadraturism emerges not merely as a decorative language, but as a technical and theoretical tool capable of influencing the perception of architectural space. It consists of "representations of architecture that, by exploiting at times linear perspective, at times aerial perspective and other devices, induce in the viewer a perception of depth that 'breaks through' the wall surface, expanding the space that contains them to the limits of sight" [Migliari 2014, p. 1].
Quadraturism has its roots in the illusionistic devices already present in the wall paintings of Roman *domus* [Mazzoleni, Pappalardo 2004; Cardone 2014; Migliari 2014] –in the so-called Second and Fourth Pompeian Styles– particularly in the *cubicula*, where the small chamber intended for rest appeared larger thanks to the illusory breaking through the wall's physical boundary.
The perspectival device of quadraturism is based on the integration of two complementary perceptual modes: *perspectiva naturalis*, linked to the empirical perception of space by the observer, and *perspectiva artificialis*, constructed according to codified and controllable geometric rules. The *quadratura* expands and alters the logical structure of space, since the painted architectures –inserted within a rigorous perspectival framework– imply the intention to create a structure, or a set of structures, as a substitute for the real one or in close relationship with it [Pascariello 2005, p. 15]. In this sense, although originating from illusory needs, the *quadratura* is based on a rational and planned system, configuring itself as true designed space whose perception depends on the choice of the viewpoint. It is capable of transforming real spaces with defined boundaries into architectural 'breakthroughs', imbued with new meanings and sensations: the observer is invited to enter and ideally traverse them with their gaze, in a whirlwind of dynamism that generally favors circular movement around the room [Aterini 2015, p. 428]. The illusory effectiveness of a *quadratura*, therefore, does not lie so much in pictorial realism, but in the ability to generate an *architectura picta* consistent with the static, geometric, and perspectival principles inherent to the real construction. This principle of internal coherence allows a dialogue between real architecture and painted architecture, where one credibly and functionally extends into the other. The quadraturist representation thus becomes a 'unrevealing drawing': it shows and makes visible a spatial structure that does not physically exist but is logically plausible, while simultaneously concealing the two-dimensional physical surface it occupies, overwriting it.
In the Sala delle Guardie of the Royal Palace of Portici, the painted architectural structures effectively carry out a true rewriting of the physical space: the wall, the vaulted surface, and the corner cease to be static boundaries and become thresholds that can be visually crossed, beyond which the painted image illusionistically multiplies the spaces. This is achieved also through a careful imitation of the architectural style of the real spaces, reproducing schemes of columns, pilasters, arches, capitals, pillars, impost lines, and proportions.
The observer is thus guided through an expanded spatial experience, in which the painted architectures appear as a necessary extension of the real walls: the intention is to imagine and represent the simulated space as an integral part of the real space that contains it, with the clear aim of reconstructing the illusory architecture and connect it to the actual one [Migliari 1999]. The illusory effect, in fact, becomes more effective the more structurally coherent it is –not a *trompe-l'œil* for its own sake, but a visual construction that entails a compositional intelligence grounded in shared architectural principles. In this sense, quadraturism presents itself as a revealing tool even before being an aesthetic one: through perspective drawing, painting unveils what architecture cannot physically achieve, disclosing a structural potential 'beyond' the walls. The perspective grid, invisible yet rigorous, acts as the generative framework of the painted space –a structure that does not

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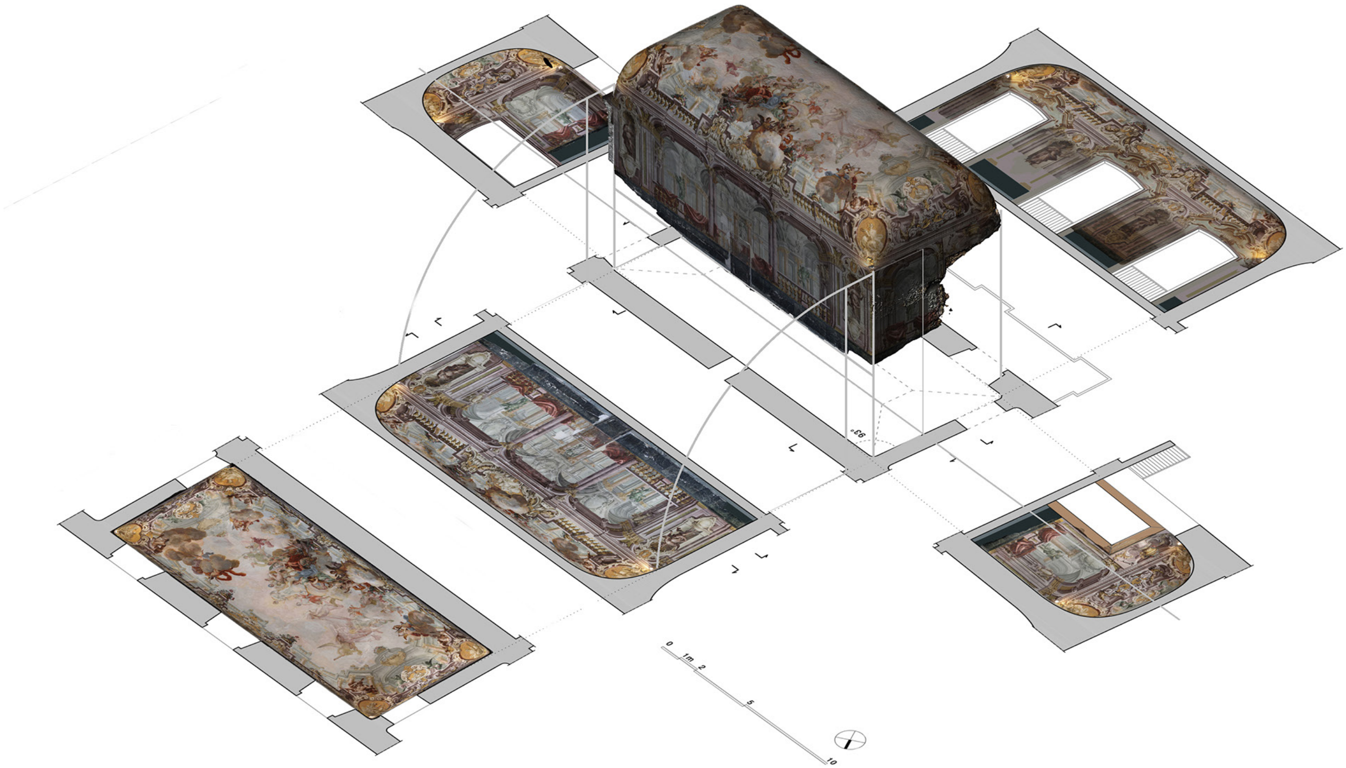


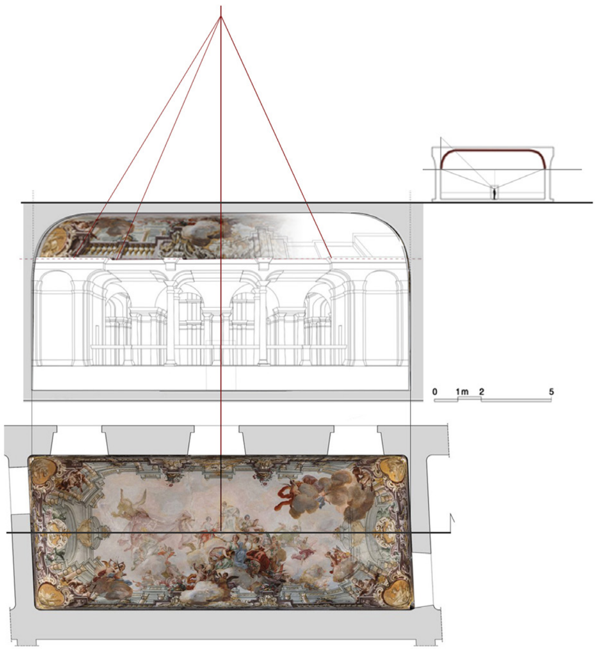
Fig. 1. Monge projections obtained from the mesh model with high-definition textures (graphic elaboration by the authors).

bear weight but imposes order, sustaining the coherence of the architectural image and guiding its perception. This tension between the built and the represented architecture is what makes the Sala delle Guardie an emblematic example of 'revealed structure', not in the technical sense of load-bearing capacity, but in the deeper one of drawing as an act of knowledge, interpretation, and organization of visible space. In this context, perspective drawing is not a mere mimetic tool, but a mediator between idea and perception, capable of revealing the invisible order that governs and sustains architectural appearance.

Drawing as structure of the illusory space

The relationship between painted spaces and real architecture is based on drawing as a means of expanding spatial experience through perception. Drawing is, in fact, the latent structure of the two liminal spaces: the painted one, which draws from the form of the real one those hidden laws and geometric relationships that rule the illusory project aimed at the verisimilitude. Perspective drawing, however, becomes an autonomous language because it is capable of generating architectural shapes that are completely non-existent in physical reality but perfectly coherent in the world of appearance. In this sense, drawing has been a design tool for the set designer Vincenzo Re in the Sala delle Guardie and a sort of 'revelation' for the scholar who wants to understand the compositional rules, but also the inevitable exceptions, of an 'other' space, investigated through the geometry that retraces the illusionistic construction of its configuration. The fundamental tools of this ancient practice of investigating painted architecture are primarily the linear conical perspective, in its reverse process that goes from the image to the true shape of the space through central projections, but also the in-depth analysis and knowledge of the architectural stylistic features of real space, which inspire the painted ones to achieve the perception of a unique architectural whole, with overall formal harmony, but with an amplified effect of depth.
The recognizability of the formal qualities of the painted space is one of the factors that determines the observer's voluntary fall into illusion. There is no doubt that the absence of static and structural problems grants freedom to the design of painted spaces, in which perspective drawing is the structure of the represented space, to

Fig. 2. Bottom orthographic projection of the pavilion vault and section, with identification of the privileged viewpoint (graphic elaboration by the authors).



be derogated according to pictorial and compositional principles without altering the overall scheme.
In the case of the perception of an architectural *quadratura*, it is essential to refer to the distinction Immanuel Kant makes between the terms 'illusion' and 'deception' in relation to sensory and transcendental appearances.
Cassandra Basile states that the term 'illusion' is associated with an awareness by the subject who evaluates an object or situation [Basile 2018, p. 416].
Once any sensory appearance is discovered, Kant refers to it as an 'illusion' in order to highlight its harmlessness for the subject perceiving it, who is aware and therefore able to judge the observed object correctly.
The correct judgment does not make the appearance disappear, but it remains as an illusion [Basile 2018, p. 416], emphasizing the game that involves the observer in appreciating the sensory illusion even when he understands that the presumed object is not real. The question, therefore, of the architectural consistency of the painted

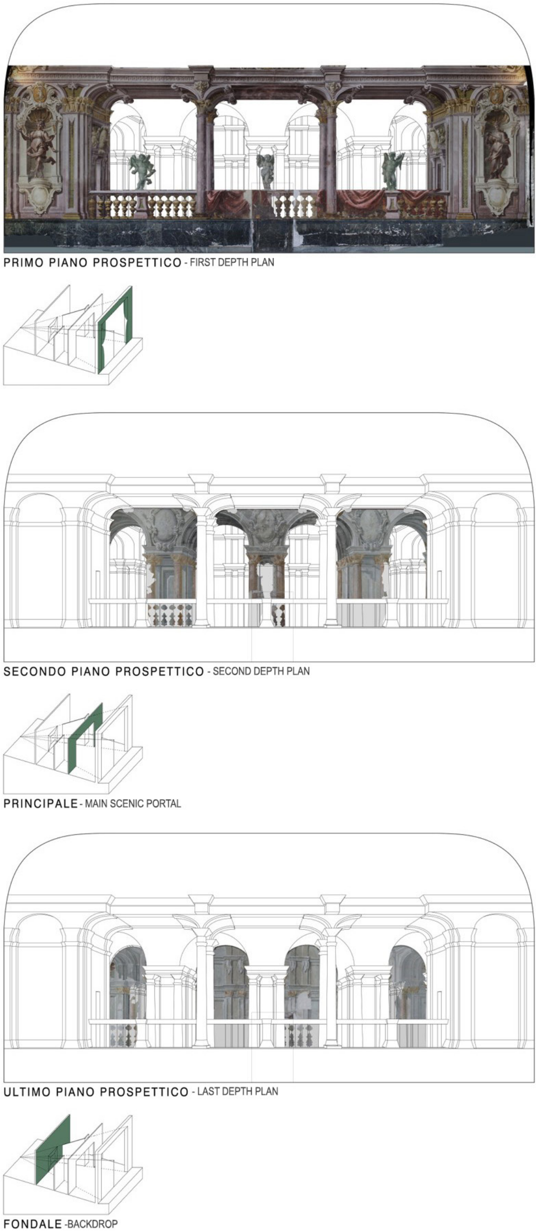


Fig. 3. Identification of depth planes (graphic elaboration by the authors).

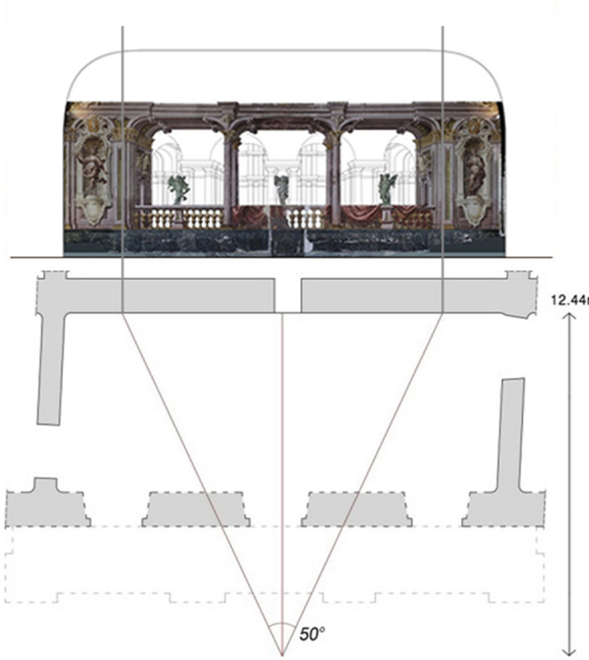
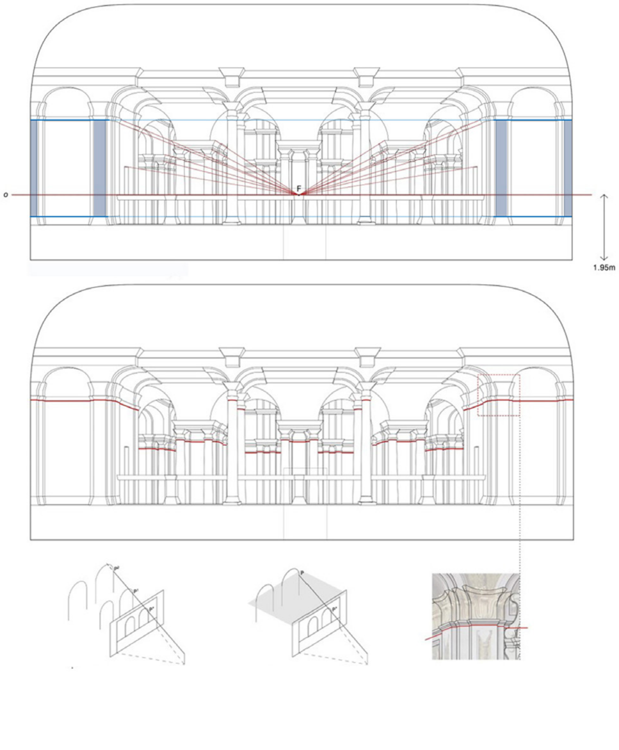
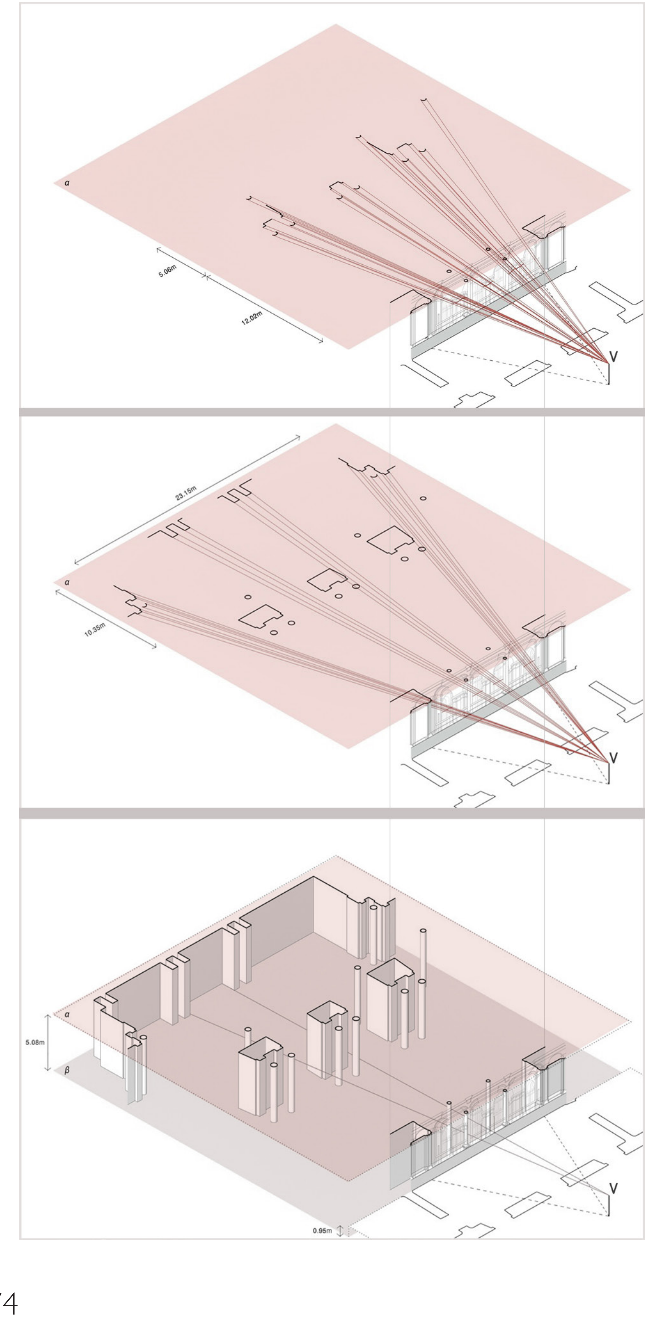


Fig. 4. Identification of the center of projection through simulation of the cone of vision in the three-dimensional space of the model (graphic elaboration by the authors).

Fig. 5. Identification of the horizon line, the pilasters aligned with the perspective frame, and the horizontal elements intended to be placed at the same level (graphic elaboration by the authors).

Fig. 6. Projection of the painted elements onto the horizontal plane to define their spatial placement (graphic elaboration by the authors).





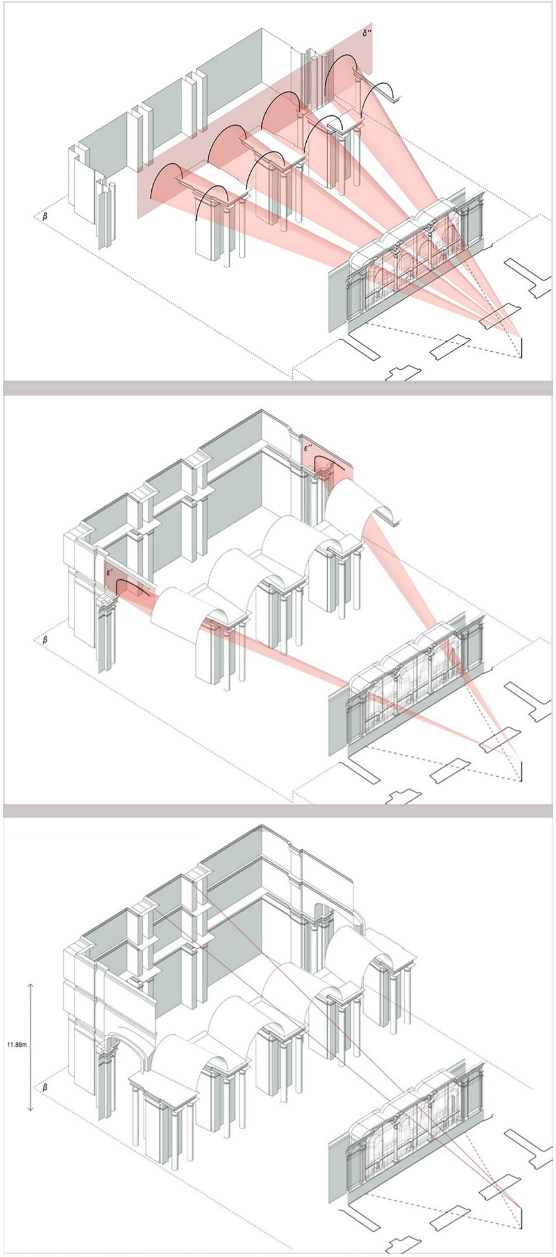


Fig. 7. Perspective reconstruction of additional painted architectural elements through the perspective alignments between the projection center, the perspective image, and the spatial position consistent with the previously reconstructed architectural elements (graphic elaboration by the authors).

space with the real one of the architecture that frames it was the fundamental critical-interpretative position of our approach in defining those painted elements that could be recognized in a spatial relationship with their counterparts in the physical space.

In order to obtain a three-dimensional model recording both the shape and spatial positioning of the real physical elements and of the perspective painted ones, a digital photogrammetric survey was carried out in the room (165 photos taken with a Canon EOS 250 D camera, with 70% partial overlap, then processed using *Metashape* software and scaled according to the direct survey data). A textured polygonal mesh model was thus prepared on which to work, in reverse perspective rendering method, i.e., by applying the same projective processes that led to the painted architectural image but spatializing these processes in the three-dimensionality of the digital model. Once the plants, sections, and the reflected ceiling plan of the vaulted surface had been obtained by the 3D model, it was possible to work on the true shape of each painted wall (fig. 1).

The presence of a frescoed vaulted ceiling with an illusionary zenithal perspective prompted us to place its projection center in the middle of the room, at a height of 150 cm from the floor; from this position, the illusory decorations projected onto the vaulted ceiling, which simulate a break-through of the covering surface, give the observer the perception that the height of the vertical walls is more than the actual height of the room.

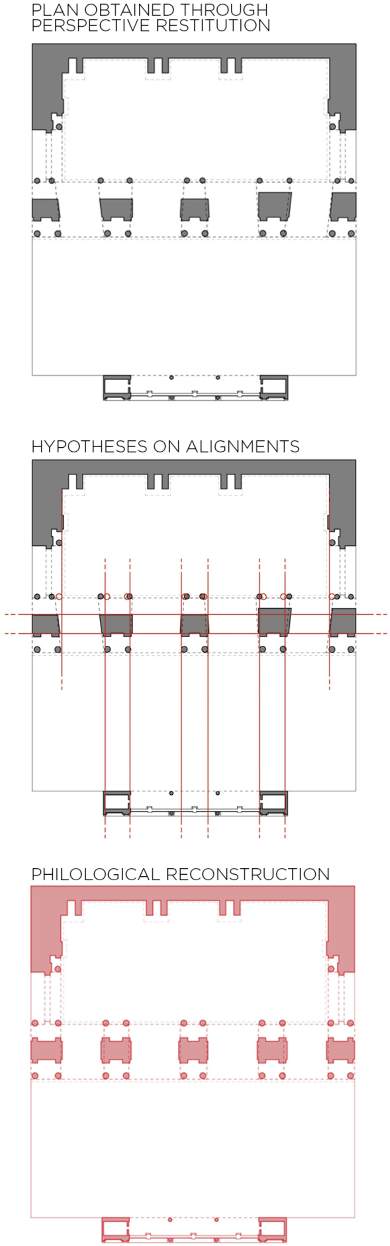
With respect to the viewpoint thus determined, the perspective painted on the pavilion vault presents a bilateral symmetry, thus validating the chosen position for the projective center/observer, which is, moreover, the one traditionally most used by quadraturist painters (fig. 2).

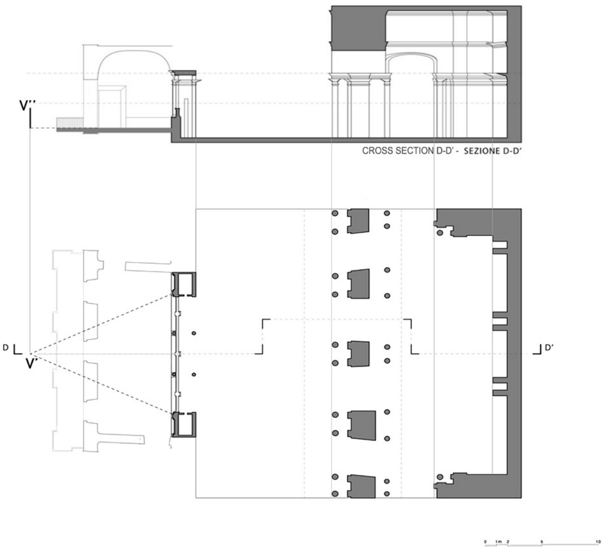
The horizon line was identified by the convergence of lines that are the perspective image of the perpendiculars to the frame; point V_0 falls, as expected, along the vertical midline of the wall, at the intersection with the upper line of the balustrade.

Drawing thus becomes structure, in the wider sense of the term, as the set of elements that constitutes an organic system thanks to their mutual relationships

Fig. 8. Plan and section of the painted space reconstructed from the wall in a frontal position relative to the windows of the room (graphic elaboration by the authors).

Fig. 9. Comparison between the reconstructed plan and the philologically reconstructed plan, elaborated based on hypotheses concerning the spatial logic underlying the artist's perspective design (graphic elaboration by the authors).

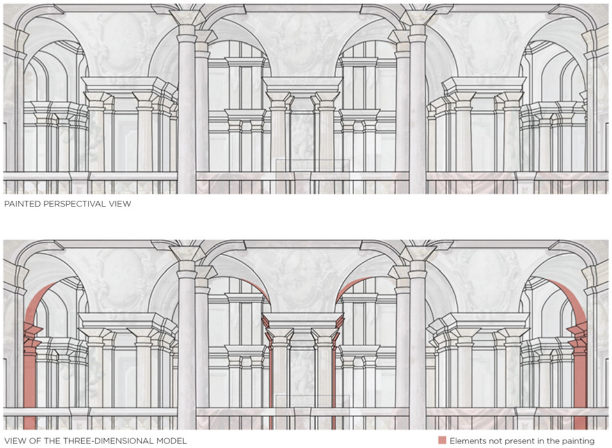




of dependence. If structure is therefore the organized complex of the parts of an organism, a construction, or a system, considered in their mutual relationships, the perspective drawing of the *Quadratura* becomes the structure of two topologically different but apparently connected and uniform spaces. The various planes of depth along which the rows of columns and arches are arranged have been discretized, thanks to an interpretation inspired by the principles of contemporary theatrical scenography (fig. 3), according to layers of depth parallel to the perspective frame, thus retracing the rich tradition of 17th and 18th century sketches, with which the scenographer Vincenzo Re was deeply familiar and from which he certainly drew inspiration.

The first necessary step in the restitution of the true shape of the painted architecture was to complete the identification of the internal orientation of the perspective reference and, therefore, the position of viewpoint *V,* which coincides with the center of projection. We noticed that an observer standing in the center of the room, the ideal position for the aforementioned zenithal perspective along the vaulted ceiling, would not have been able to see at a glance the entire wall corresponding to the long side of the room, as a consequence of the physiological limits of the visual cone, established in literature as maximum 60°.

Fig. 10. Comparison between the perspective image painted on the room wall and the corresponding view of the 3D model, obtained from the philological reconstruction and observed from the same viewpoint (graphic elaboration by the authors).



According to the scenography main rules established by Serlio [Serlio 1545], as well as by many other later treatisers, the ideal viewpoint of a stage setting, or the privileged observer (which coincides with the center of projection of the entire perspective system), is frequently placed outside the physical space of the theatre building, thereby reducing the effect of perspective distortions for less privileged observers who are positioned to the side. Similarly, Vincenzo Re placed his projection center beyond the boundary of the room, in the contiguous space. The position was identified considering that the entire wall falls within the 60° visual cone and that the painted second plane of depth is contained within a 50° visual angle. The hypothesis was verified by placing a digital camera in the 3D model of the room (fig. 4). Again, according to an interpretation based on the illusionistic stage design principles, it was noted that the perspective floor plan coincides with the horizon line. This choice comes from the stage setting tradition, described by Ferdinando Galli Bibiena in his 1732 treatise, *Direzioni della prospettiva teorica corrispondenti a quelle dell'architettura, istruzione a' giovani studenti di pittura, e architettura nell'Accademia clementina dell'Instituto delle Scienze*, table No. 49, useful for adapting architectural perspectives to the two-dimensionality of the painted canvas that rests on the stage with a straight base [Pagliano 2016]. Since there are no physical elements protruding sculpturally from the wall, such as pilasters, moldings, or capitals, we chose to place the image plane in coincidence with the pilasters in the foreground (fig. 5), which are thus considered to be in their true form and size.

Starting from these elements, we placed one horizontal plane at the height of the collar of these pillars in the foreground, onto which we projected, from point *V* all the other painted collars at a different depth plane, assuming that they were at the same height, in accordance with the architectural consistency of the painted space (fig. 6).

According to this hypothesis, the perspective restitution was carried out by running in reverse order the conical projections that have been necessary to Vincenzo Re for the construction of the perspective image, thus spatializing in a digital 3D model those geometric processes typically drawn in 2D, through the descriptive geometry's methods (fig. 7).

Using a similar process, the true shape of the painted spaces on the other walls of the room has been reconstructed. Each wall has its own projection center, but they are all the same height, as can be seen from the horizon lines on each wall, which are all at the same height from the floor. This geometric expedient has a highly effective illusory effect, as the observer perceives the painted space as a single, coherent architectural system (fig. 8), an external space concentric to that of the Guard Room, which appears to surround the room on all four sides, being visible through the filter of the arches painted in the foreground.

The revealed space and its augmented fruition

Extended Reality (XR) technologies are increasingly emerging as tools of primary scientific and applicative relevance in the field of Cultural Heritage communication. They are now widely implemented in museums as well as in historical and archaeological sites worldwide [Innocente et al. 2023], with the purpose of providing visitors with interactive and immersive experiences [Casale 2018]. Among these technologies, AR (Augmented Reality) and VR (Virtual Reality) represent two of the most significant developments, functioning as privileged instruments not only for the enhancement and fruition of Cultural Heritage in a broad sense, but also for the analysis and interpretation of painted architectures, as exemplified by the case of *quadratura*. The advantages of interactive digital visualization range from cultural and physical accessibility to interpretation, engagement, and inclusive communication [Pagliano 2023]. Indeed, the interaction with virtual spaces and objects contributes to the promotion of cultural heritage and enhances understanding of the site, fostering critical feedback and increasing awareness [Innocente et al. 2023].
The construction of the three-dimensional model derived from the perspective restitution of the painted architectures in the Sala delle Guardie represents the starting point for a broader reflection on the interaction between illusionistic space and digital technologies. One of the most significant aspects that emerged during the modeling process concerns the necessity of reconstructing, beyond the architectural frames delimiting the scene, a continuous and coherent space. Indeed, the painted architecture is conceived in continuity with the real architecture of the Royal Palace, echoing its style, architectural layout, and proportions, while also respecting the height of the springing line of the vaults. It should be noted, however, that a careful philological reconstruction of the drawings obtained through perspective restitution was required in order to correct a series of spatial inconsistencies. In some cases, the reconstructed plan deviated from what would be architecturally plausible: for instance, a trapezoidal section of the pillar plan, rather than a rectangular one, contradicted the spatial logic that the painter had in all likelihood conceived according to coherent canons and stylistic principles. For this reason, the space was 'rectified' in those areas where only minor discrepancies and geometric inconsistencies were detected –conditions that would have been incompatible with a functional and feasible architectural structure (figs. 9, 10). This operation proved necessary because the *quadratura*, although appearing perfectly regular from a perspectival point of view, would inevitably reveal, when observed from other viewpoints, optical adjustments and distortions devised to serve the pictorial illusion –yet impossible to translate into a three-dimensional structure governed by logical consistency. The adoption of AR and VR technologies, which allow users to freely vary their point of view and to 'enter' the space, makes it essential to employ a model free from structural inconsistencies. Otherwise, the user would perceive distortions which, although legitimate on the painted surface, would appear disturbing and misleading within the immersive experience.
By positioning virtual cameras, it becomes possible to inhabit the model as if it were a real space (fig. 11), thereby simulating the experience of the historical viewer and even surpassing it by detaching oneself from the privileged viewpoint. The virtual dimension allows "to investigate the space of the hypothetical, going beyond the single and finite point of view of perspectival representation" [Pascariello 2005, p. 20]. The freedom to vary the position of the observer required, in fact, an additional interpretative effort aimed at achieving a philological reconstruction of those portions not visible from the main viewpoint and therefore not directly recoverable. It is precisely in these 'perceptual overflows' –only visible from viewpoints not originally envisaged by the artist– that the possibility of exploring the virtual three-dimensional model becomes a critical rather than merely experiential tool, revealing the design complexity underlying the pictorial illusion.
The three-dimensional model can be experienced through two different modes of interaction: AR, which allows virtual elements to be superimposed onto the real environment,

Fig. 11. Plan of the 3D model derived from the philological reconstruction, integrated with parts not visible in the painting and reconstructed based on interpretative hypotheses of the spatial logic (graphic elaboration by the authors).

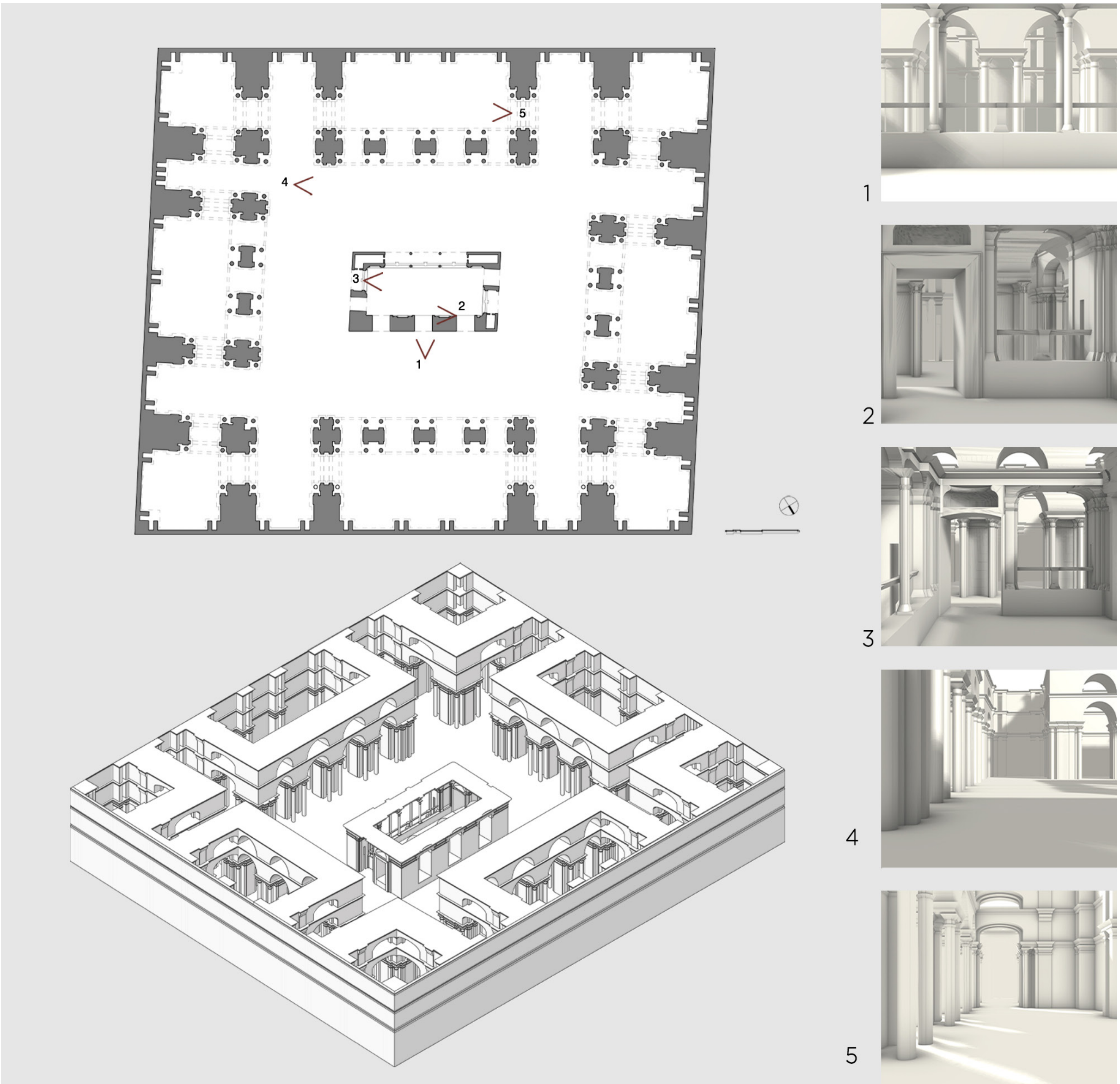


Fig. 12. Top, an example of Augmented Reality application using the quadratura itself as the target to activate digital content through the ArtiVive platform. Bottom, 360° panoramic image obtained from the three-dimensional model using Blender, employed to create an immersive VR video, available on YouTube (graphic elaboration by the authors).

thereby enriching its perception and experience; or VR, based on the use of a fully immersive environment, isolating the user from the physical world and 'immersing' them in a simulated space that can be explored in first person. Both modes of interaction enhance sensory perception by providing additional information beyond what can be directly perceived. Moreover, they enable a dynamic interaction with the heritage asset, fostering user engagement and immersiveness [Zhou et al. 2022], while also highlighting their role as privileged tools for the analysis and interpretation of space. In particular, the use of AR proves to be strategic in explicitly revealing the relationship between real and painted space, offering the observer instruments for critical and informed interpretation. AR makes it possible not only to explore the revealed pictorial space from different angles, but also to challenge the perceptual stability of the frontal vision traditionally imposed by the single viewpoint, allowing for the analysis and verification of spatial hypotheses and configurations (fig. 12) while standing before the painted work.
While AR provides only partially immersive interaction, VR is instead capable of ensuring the highest degree of immersiveness, embodying an advanced integration between technology and perception that deliver experiences transcending the boundaries of physical reality [Camagni 2024, p. 137]. Its main purpose is to reproduce a condition of virtual presence –that is, to generate in users the impression of actually being inside the digital environment and of experiencing it through their senses (primarily sight, but also hearing and, at times, touch). In its less complex and easily applicable form, it is necessary to create one or more 360° spherical images of the three-dimensional model, which can then be set up using dedicated applications in the form of a virtual tour (e.g., *Lapentor*) or an immersive video (fig. 12), incorporating interactive hot spots and additional multimedia content.
The integration of the three-dimensional model within AR environments –accessible through mobile devices– and VR environments –experienced via immersive headsets, stereoscopic viewers, or other dedicated peripherals– offers a multilayered form of exploration. On the one hand, it preserves the historical visual experience, anchored to the original, frontal, and centralized viewpoint; on the other, it reveals the underlying perspective apparatus, articulated across multiple perceptual levels and 'navigable' from diverse viewpoints, exposing its limits, ruptures, and spatial reconstructions. AR and VR thus become instruments of mediation between perception and construction, between what is shown and what is implied, between real and possible space. This approach allows the viewer to 'enter' the perspective illusion conceived by the artists, while simultaneously revealing the perspectival artifices and internal spatial relationships. It also provides both an immersive experience and a critical framework for interpreting the geometric processes of perspective projection. In this sense, digital technology functions as a methodological extension of the drawing, highlighting its structural, projective, and cognitive dimensions, and unveiling the complexity of an architectural space that is at once real, painted, and imagined.

Conclusions

The research aimed at showing how drawing is the preferred tool for investigating the spatial structure of the illusory architecture painted in the Guard Room of the Bourbon Royal Palace in Portici. The geometric analysis of the painted *quadratura* allowed us to recognize the consistency of the illusory design with respect to the real space that houses it, while at the same time highlighting the compositional freedom afforded by the absence of any static or structural constraints. Drawing takes on a revealing role: it allows us to uncover the rules and exceptions that govern the construction of painted depth, restoring the harmony of a system in which real architectural space and perspective space are integrated into a single organism through drawing. The structures identified not only make the logic of the project legible but also confirm the function of drawing as a medium through which the invisible takes shape and becomes perceptible. While in the original experience the observer was bound to a specific viewpoint, a restricted and above all static view, today's digital technologies allow us to overcome this limitation. Three-dimensional restoration and reconstruction in a digital environment, together with the potential of AR and VR, opens new possibilities for critical exploration and expanded enjoyment of cultural heritage, providing the complexity of the illusory space in an accessible version and highlighting the architectural coherence that underlies it. The result is that drawing as a design tool, both analog and digital, not only documents and interprets Baroque *quadrature*, but also makes them accessible and legible, revealing the hidden structure that supports their scenographic and spatial effectiveness.

Credits

The authors wish to thank Dario Silvestri for his work on the digital survey and three-dimensional modeling of the reconstructed architectures. Although the paper is the result of a joint research effort, Barbara Ansaldi is the author of the *Introduction* and Sections *Architecture as a frame for painted spaces: quadraturism and space beyond physical boundaries* and *The revealed space and its augmented fruition*, while Alessandra Pagliano is the author of Section *Drawing as structure of the illusory space* and the *Conclusions*.

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Drawing the Structure. Codes, Methods, and Tools

Which Structure

Luigi Cocchiarella

Introduction

Research and applications of graphic representation largely concern the 'design' of form. Form is, in fact, the powerful reference, the attractor toward which the processes of knowledge acquisition and design generation tend to converge. Research and applications on the structure instead, which nevertheless supports the form, is sometimes less evident, either because it is somehow taken for granted and considered less relevant than the corresponding formal outcomes, or because it remains hidden behind a certain intellectual secrecy, not always naïve. The topic of codes, methods, and tools adopted in the work on the structure, therefore offers an interesting frame for further explorations.
But which structure?

The term has a very general meaning, however, with specific reference to architecture, it can be considered in relation to the spatial dimension, and therefore to Geometry as a control structure of that dimension through Representation. In turn, architectural space is a particular subset of the abstract space, both in dimensional and substantial terms. The first limitation is banal, given that, although the William Morris's definition has invested the entire Earth's crust with potential architectural connotations, it is still a limited field compared to the theoretical extension of pure geometric space. The second one requires some further reflection, since architectural space, although endowed with geometric characteristics, is not a purely metric

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space, but it is qualified by the human presence. It is rather an existential space, as Christian Norberg-Schulz has well clarified [Norberg-Schulz 1996]. And yet, despite these limitations, the field of investigation remains broad. Renato De Fusco, among others, offers a convincing example of this in his delightful book *Architecturminimum* [De Fusco 2010]. In the chapter on "*spazialismo*," he compares Bruno Zevi's position, according to which anything lacking physically usable internal space should be excluded from the field of architecture, with the less radical and more inclusive opinion of August Schmarsow, who, based on also considering intellectual and spiritual values, admits that even inaccessible constructions can legitimately be considered architecture. The example of the Greek temple is quite convincing in this regard [De Fusco 2010, pp. 46-51]. Accepting this axiom, greatly broadens the spectrum of the configurations of interest for geometric research in architecture and, as we will see, it is somehow in line with the findings of artificial intelligence on this subject. Moreover, Erwin Panofsky, in his epochal essay *Perspective as 'Symbolic Form'*, had already theorized the spatial unity between architecture and sculptural masses, also highlighting the decisive role that this concept would have played in the development of perspective in painting [Panofsky 1997]. And by extension, we could add, in the development of the projective forms of representation, intended as privileged devices for the graphic control of the geometric structures, the validity of which is increasingly confirmed, and not only in architecture, in the era of digital visualization and simulation.

A latent presence

The inextricable connection between form and structure is immediately evident, even from the earliest experiments with perspective, primarily showing in the sinopia as the latent essential support structuring the pictorial composition (fig. 1). Piero Della Francesca himself, one of the most sensitive initiators, recommended first defining the perspective skeleton, that is the configuration pattern, which would then be coated with the pigment to express the final visible form. This approach has survived the analog era and been revived in the digital world, where the wireframe or mesh modeling of the geometric structure offer the basis for rendering the apparent material qualities.

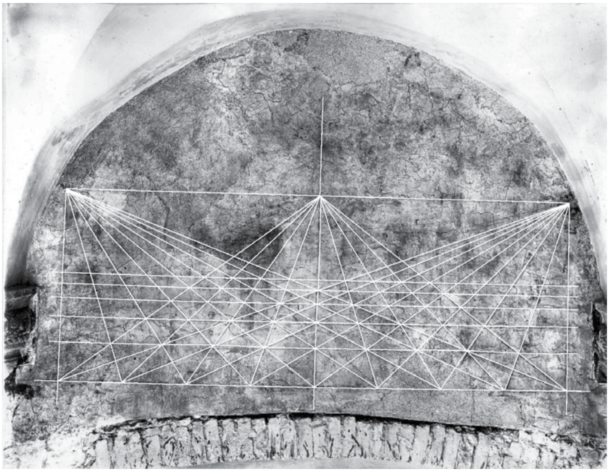

Fig. 1. Paolo Uccello, sinopia of the Nativity of Jesus (1446). Source: <https://catalogo.beniculturali.it/detail/HistoricOrArtisticProperty/0900285185> (accessed 5 December 2025). (Graphic elaboration by the author).

The concept of structure has become more precise over time, especially in the field of linguistics, where, starting in the first decade of the Twentieth century, it began to identify a field of study known as *Structuralism*. Renato De Fusco, again, noted that the basic notions of "organization" and "abstraction" come into play in this field [De Fusco 2010, pp. 66-70]. In the last two decades of the Twentieth century, this theory also received experimental confirmation on the cognitive level. Thanks to research conducted in those years at the Massachusetts Institute of Technology by the scholars Susan Carey and Nancy Soya on the language of children under three years of age, it emerged that infant lexical and syntactic learning revealed the existence of recurring mental structures, which, beyond the specific language spoken, would lead to at least a partial reconsideration of the principle of linguistic arbitrariness advocated by Willard Van Orman Quine. It is curious to note that this significant contribution to the development of a new theory of mind based on the recognition of cognitive structures, occurred precisely at the same time as a certain weariness of the structuralist movement in architecture, now on the way out due to its abstract determinism [Cocchiarella 2012, pp. 103-117]. On the other hand, in the wake of Albert Einstein's thought, the awareness that the entire physical world is characterized by structure persisted. And soon, the World Wide Web would in addition demonstrate the potential of information structures. In a certain sense, the Twentieth century trajectory and the subsequent developments of the Neo-structuralism at the dawn of the new millennium showed a substantial structural coherence between the levels of thought, reality, and representations, which Karl Popper identified as the three fundamental worlds, of which the world of representations, to which Drawing most closely belongs, constitutes the connecting link –in his words, a properly said third world. A revolutionary explanation compared to the dominant Platonic dualism in vogue in the Western world, apart from the warning implicit in the Myth of the Cave.
With reference to architecture, the concept of structure, in the synthetic terms used by Renato De Fusco, takes us beyond the visible. In this sense, it would therefore identify the configurative organization that defines the essence of a given space or category of spaces.

Biographic warning

The author of this essay, was educated in the second half of the 1980s, a period in which the structuralist approach had been fully embraced in some Italian university Schools. An undisputed pioneer, Anna Sgrosso, professor of Drawing and Surveying, and of Fundamentals of Descriptive Geometry at the University of Naples Federico II, was among the first teacher experimenting with analogue graphic interpretations aimed at highlighting, through appropriate 'transparency' effects, the geometric structure of the architectural spaces, which became evident once the masonry masses were visually lightened in the representation [Sgrosso 1984]. Despite the considerable aesthetic appeal of the resulting unusual images, made even clearer and more compelling by the use of translucent colored adhesive filters applied onto acetate bases to highlight the essential generating surfaces, the cognitive contribution of this approach, which allowed architectural spaces to be displayed and interpreted simultaneously from 'the outside' and 'the inside' thanks to carefully studied graphic and chromatic transparencies, left an indelible legacy in the 'students-architects' (as she used) of those years. Even more importantly, these applications directly revealed the interplay between the mentioned abstraction and organization levels, that we considered to be the foundation of the very concept of structure. By making evident the action of (abstract) geometric structures in the configuration of the (specific) physical spaces represented, the perception of a gap between theory and practice, a barrier usually difficult to overcome in teaching, naturally faded as well. This vision, shared at an interdisciplinary level, led to the establishment of a University Department that promoted it in its very name: the Dipartimento di Configurazione e Attuazione dell'Architettura. The theme of configuration was thus taken up in the design disciplines in a pre-figurative and, more generally, in a meta-design perspective, and assumed as one of the relevant foundations of the design process (fig. 2).

Substantial continuity

These experiments were also in line with the forms of digital representation, particularly vector-based, emerging with the widespread use of personal computers, and

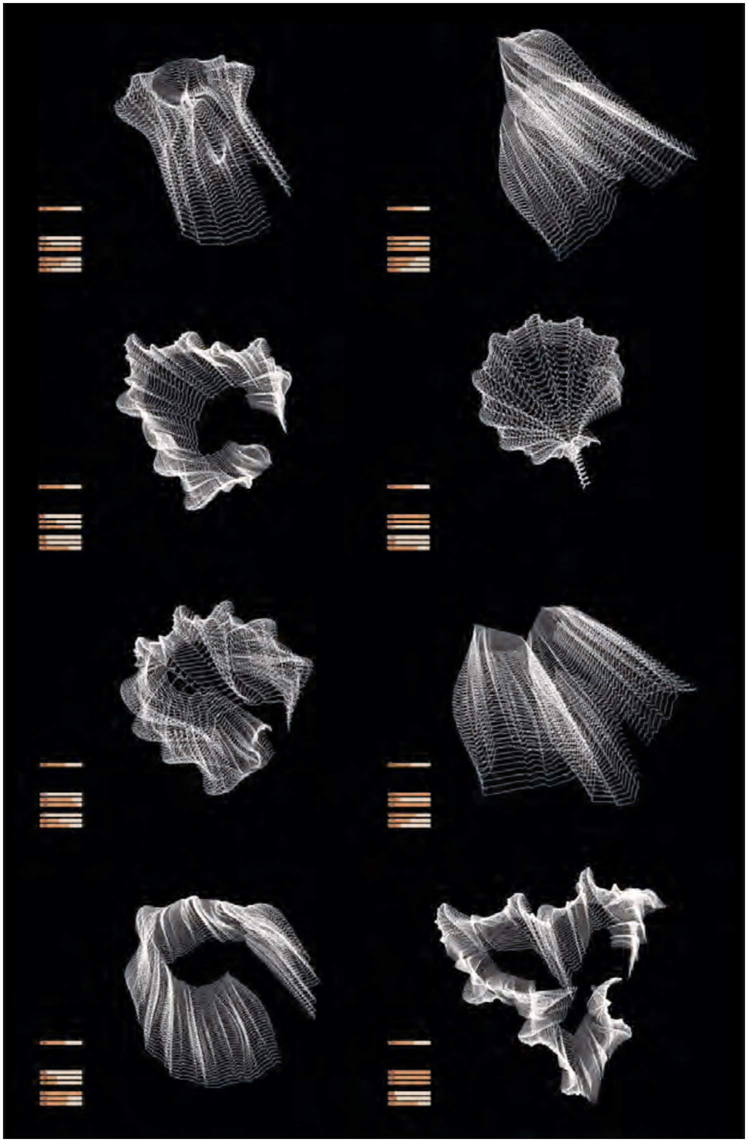

Fig. 2. Parametric variations based on the same geometric structure. Benjamin Dillenburger, Hua Hao (ETH). Source: Cornelie Leopold, Università Tecnica di Kaiserslautern (Eds.). (2013). A hermit's cabin: [Erasmus intensive programme, Kaiserslautern]. Kaiserslautern: Technische Universität, p. 31.

consequently of digital drawing and modeling software programs. The most obvious affinity concerned, again, the relationship between structure and form. The hidden lines of traditional drawing were now used to show hidden lines, surfaces, and volumes, as components of the geometric-structural skeleton, subsequently covered by the rendering patterns in the advanced stages of the three-dimensional modeling.

In essence, digital graphic representation further confirmed the validity of the concept of structure, both with reference to the form of architectural space and to the forms of its representation. Regarding the first point, so-called 3D modeling required the construction, in a software environment, of the entire architectural space –that is, of every angle or detail, and not just a few views, or projections, as it was used to do in the past. In this way, properly said 3D models were generated, which could subsequently be viewed as images from every possible viewing point: we had defined this new concept as model-image, completely opposed to the analog image-model, which consisted of a certain number of views from which the actual form of the space could be deduced, but only indirectly, by a mental reconstruction [Cocchiarella 2006, pp. 183-197]. This novel approach, until then only experimented in the construction of physical *maquettes*, required the preliminary construction of a schematic, that is abstract, geometric model of the space investigated, based on the consideration of its overall organization; in other words, it made it impossible to ignore the identification of its structure. Regarding the second aspect, the uniqueness of the model allowed for multiple simultaneous visualizations, each in its own graphic area or viewport, updating synchronously with all the other views with every change in shape or position made to the model. In other words, the editing of the model implied a coherent reorganization of the views. This demonstrates the structural value of the projective form as well, regardless of its declination according to the conical or cylindrical regimes. To generalize, the structure of space was revealed not only in the Euclidean and Projective fields, but also in their correspondence.

This brought with it a new expressive code, or rather, an expansion of the classical static semiological figures, such as plan, section, axonometric projection, and perspective, now transformed into temporary shots generated from a model that was also potentially in constant transformation, within a dynamic operational space that appeared now as a truly digital stage.

Once the correspondence between physical and digital space was established, geometric structures controllable via software soon transcended the Euclidean and Projective fields, extending into other geometric fields. Indeed, upon closer inspection, the programming language underlying visual processing itself, rested on a mathematical logical structure, which by its very nature was widely adaptable. Among the most interesting extensions is that concerning topological structures and their management through NURBS curves and surfaces [Ciammaichella 2002; Brevi 2004]. The most surprising aspect for those accustomed to traditional disciplinary divisions, was undoubtedly the near-total absence of discontinuity in the transition from the Euclidean, Projective, and Topological fields. This paved the way for an intense period of design experimentation based on morphing, thus further emphasizing the relationship between structure and form –that is, the relationship between organization, abstraction, and form– to recall the previously introduced notions. Architectural structuralism itself experienced a new era, leveraging new tools and procedures to capitalize on what had previously been experimented in the analogue way, and to propose new advances from a front soon identified as Neo-structuralist, as it was mentioned before (Fig. 3).

Visuality and beyond

Another interesting stylistic innovation concerned the possibility, translating the Cartesian approach into a digital subspecies, to easily and interactively connect numerical and graphic structures, thus drawing with numbers and generating numbers by drawing. As predicted by Michael Foucault and later noted by Régis Debray, digital technology was gradually shifting the level of processing to a visual level. New graphical interfaces allowed programming, within certain limits, by operating on highly intuitive graph structures rather than through traditional machine language codes. With regard to the theme of "revealed structure", this is perhaps the most innovative step, since through the introduction and rapid widespread diffusion of visual programming, the very structure of spatial thought was exposed, shedding light on the generative process underlying the spatial elaborations. We are thus at the stage of parametric modeling, an approach that, like theoretical abstraction, allows us to manipulate the

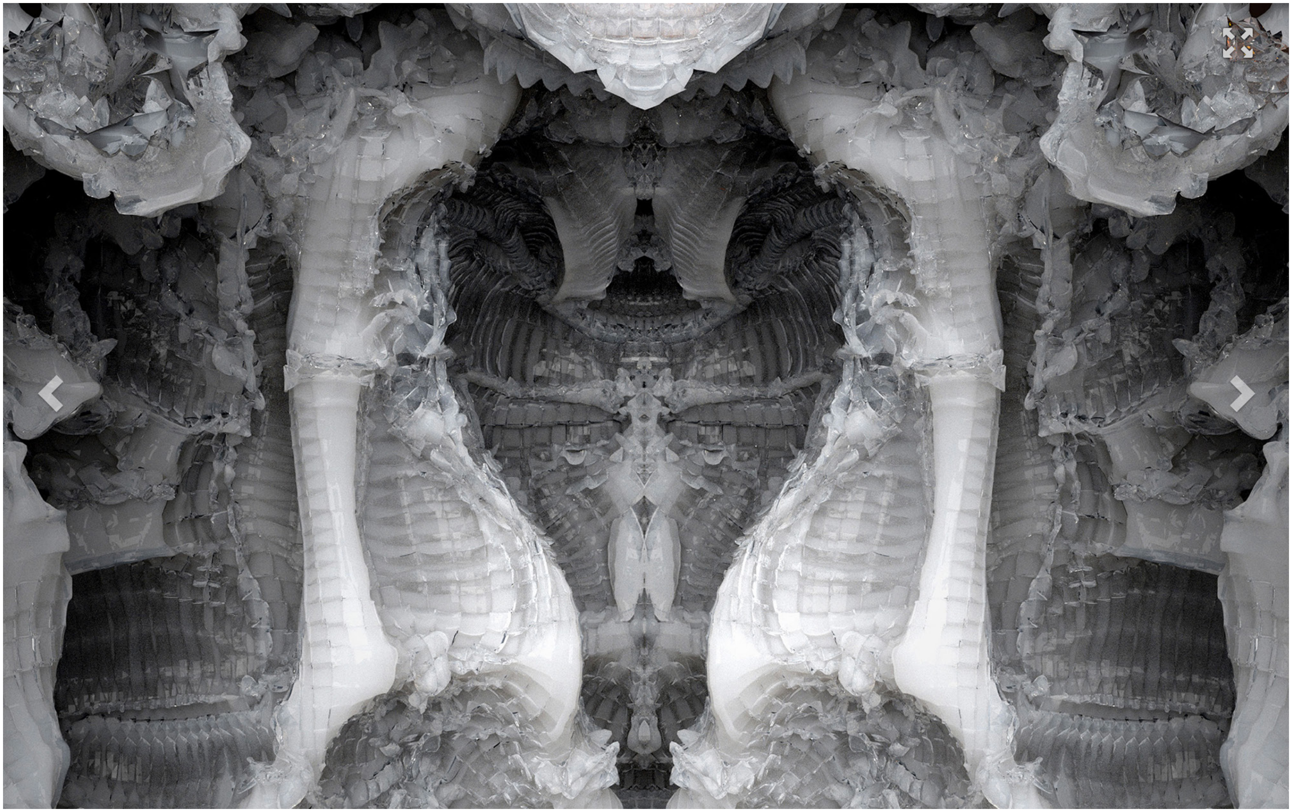

Fig. 3. Digital Grotesque I (2013). Michael Hansmeyer with Benjiamin Dillenburger. Source: <https://michael-hansmeyer.com/digital-grotesque-I> (accessed 5 December 2025).

genetic organization of the configurations and to generate virtually any formal outcome consistent with that structure –in short, to operate on the geometric-spatial genotypes underlying the multiplicity of the related formal phenotypes obtainable. This partnership helps shed new light on the foundational relationship between *logos* (let's say logical thinking and expression) and *graphè* (let's say visual thinking and expression) [Ugo 1984].

Thus far, these advances have focused on the control of the geometric properties of architectural space and the launch of new operating methods related to computational design. Further developments in parametric modeling have subsequently allowed for the addition of further, non-geometric attributes, to the configurations. Upon closer inspection, rendering itself marks a first step in this direction, albeit still on a purely visual level, surpassing the simplicity of the images offered by early CAD systems, starting with the monumental *Sketchpad* developed by Ivan Sutherland. The integration of additional informative parameters, both visual and non-visual, has gradually broadened the semantic consistency of the modeling processes, leading first to thinking of them in terms of digital objects and finally of digital clones. Of the three components of representation –Geometry, Graphics, and Information– the latter is also gradually absorbed into the body of the model and interacts with it, effectively becoming an active operator [Hemmerling, Cocchiarella 2018]. Indeed, the acronym BIM (Building Information Modeling) refers not so much to the process of constructing space as to the modeling of information. Yet geometric structure provides for the essential scaffolding, without which other information systems would remain in the status of mere lists of data. On the other hand, interaction with increasingly sophisticated types of information, tends to make the structure more 'sensitive' to the specific organizational and the constitutive characteristics of the final form. In this sense, at least at a theoretical level, each set of parameters, alone or in synergy with other sets of data, can have an impact on the structure, triggering mutations that to some extent may resemble the natural evolutionary mechanisms (fig. 4).

Novel postures

Let us return to the initial theme, in the sense that this semantic enrichment is consistent with a concept of structure that embraces the richness characterizing the existential space and the vital significance of its real configurations, together with its purely metric aspects. Managing this additional level of complexity is aided by the transition from modeling to simulation, which in the most sophisticated versions can even prefigure actual scenarios, where even the temporal parameter is incorporated into the foundational structure. The most suitable context for this type of representation is undoubtedly the gaming environment, which boasts over forty years of 'ludic' testing and now offers adequate 'serious' operational bases for complex architectural space simulations.

Technologies based on virtual reality offer new possibilities for its use, in more or less hybrid environments, redefining the gradient of the relationships between physical reality and the purely digital dimension. The human-keyboard-screen posture remarked by Alessandro Baricco in the essay *The Game* [Baricco 2018], which has dominated the digital age for decades, is here replaced by freer postures, tied to haptic devices. This is a sort of Copernican revolution in the digital universe, which is now no longer confined beyond the screen, but surrounds us with its cross-media structures, where the visual dimension integrates with other sensory perceptions. Here too, and even more so, we are dealing with a structured space, whose geometric articulation, though not directly perceptible, dynamically supports semantic components that transcend the pure metric organization.

Interaction with this new environment, partly physical and partly digital, for which the neologism 'phygital' has been coined, can be programmed in various ways, reaching very realistic levels of interaction with the support of artificial intelligence.

Even in the field of artificial intelligence, a revolutionary shift has occurred, specifically in the transition from the "intelligen system" to the "intelligent agent" [Cocchiarella 2025, pp. 44-51]. While the first type of artificial intelligence relied on information previously encoded by the operator and compliant with the current linguistic codes, the new devices tend to mimic human mental processes, autonomously and directly drawing input from real-world contexts through their own sensors, without any prior linguistic mediation. Technically, new generation machine learning processes interact with symbolic codes and sub-symbolic mechanisms, and the processing phases therefore proceed therefore proceeds both parametrically and non-parametrically, learning from the context and reacting to it by adapting [Ye 2022]. Sometimes in completely

Fig. 4. Towers in the series AI x Future Cities. Courtesy of Manas Bhatia. Source: ARTRIBUNE, <https://www.artribune.com/progettazione/architettura/2022/12/intelligenza-artificiale/> (accessed 5 December 2025).

unpredictable ways (fig. 5). As for the processes currently underway, the combination of stochastic and statistical elaborations adds analytical and generative potential, whether an intelligent system or an intelligent agent is involved. The greater autonomy of artificial intelligence compared to other expressions of digital technology is increasingly leading to consider it as a partner or copilot, rather than as a mere operational tool.

Conclusion… open

The semantic enrichment that characterizes the most advanced processes of generating and managing the representation of architectural space, thus reveals an increase syncretism in the assortment of its structural foundations, shedding new light on the notions of organization and abstraction that we placed at the foundation of the very concept of structure. A structure that, at least in the architectural sphere, seems to gradually tend back toward the *form* almost to the point of coinciding with it, or more precisely, toward the digital clone of the form. Whether it be a prefigured or a surveyed form. In either case, the formidable outcomes would seem, a fist sight, to fuel the nightmare evoked by Jorge Luis Borges with the paradox of the Map of the Empire produced by the Cartographers, which was as extensive as the Empire itself, and therefore unusable. In our case, however, we are not dealing with *static clones* traced on inextensible paper, but rather with interactive environments, designed to continue to function as operational models even after reaching the desired configuration, which remains open to further formal mutations and, more importantly for us, to further evolutions, even of a self-generative type, of the deep structural system, understood in all its semantic richness [Hovestadt et al. 2020; del Campo 2024].
In conclusion, we could say that the abundance of digital, which is now added to and integrated with the abundance of nature, seems to somehow bring us back to a threshold of a quasi-new-origin, requiring a renewed attitude –one might even say philosophical– to question, with the additional support of appropriate prompts, textual or iconic, the expanded field of the real architectural contexts, and to manage the new semantic complexities characterizing the modeling of the structures underlying the existential space.

Fig. 5. DeVain, Valentino's advertising 4/12/2025 generated with AI. Source: <https://video.corriere.it/video-virali/-inquietante-e-surreale-la-pubblicita-valentino-generata-con-l-ia-finisce-nel-mirino-dei-social/417470a0-238a-471d-a979-84704af24xlk> (accessed 5 December 2025). (Graphic elaboration by the author).

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Visible Logic: Algorithmic Drawing and the Construction of Form

Leonardo Baglioni, Michele Calvano, Graziano Mario Valenti

Abstract

The paper explores algorithmic drawing as both a critical and operational tool, highlighting its capacity to transform representation into a constructive process. Drawing has always possessed a generative nature: it does not merely depict an idea but establishes its validity by gradually constructing the spatial field of form. The digital transcription of algorithmic logics amplifies this dimension, translating the graphic gesture into sequences of rules, constraints, and parameters that render the entire design chain, from conception to realization, transparent. Indirect modeling, in particular, allows form to be conceived as a relational field, where dependencies among elements define coherent behaviors under transformation. The chain of models (conceptual, exploratory, continuous, procedural, fabrication, and physical) produces not only representations but genuine constructive programs capable of integrating geometric constraints, production requirements, and performance objectives. The case studies demonstrate how algorithmic drawing enables the management of complex forms, their translation into efficient constructive systems, and the preservation of project identity through variations, a visible logic that reaffirms and enhances the constructive nature of drawing.

Keywords: algorithmic drawing, indirect modeling, generative process, constructive logic.

Introduction

Drawing has always represented far more than a mere graphic act: it constitutes the device through which the immaterial gains consistency, latent form becomes manifest, and the idea becomes verifiable. In the transition from abstraction to construction, it makes visible the logic that governs the project. In this sense, *Visible Logic: Algorithmic Drawing and the Construction of Form* is not simply a title but defines a research program [1] that conceives drawing as a cognitive and operational infrastructure, in continuity with the theoretical framework of "Drawing as Model" [Migliari 2004, p. 15].
The tradition of Descriptive Geometry has long regarded drawing as a constructive method, capable not only of visualizing but of demonstrating the existence of possible form. According to Gino Loria, construction is, like other mathematical methods, a means of existential demonstration [Loria 1935, p. 77]. Far from belonging to the past, this perspective finds renewed relevance in the digital condition, where drawing simultaneously serves as an instrument of analysis, generation, and verification [Migliari 2009, pp. 28-37].
The contemporary transition does not merely consist in the use of more powerful software, but in the transformation of drawing into process: an explicit sequence of rules, constraints, and parameters that define not only the image of form but its very genesis [Burry 2013, pp. 154-165]. Within this framework, IM (Indirect Modeling) represents the decisive shift, as it does not operate directly on finalized geometry but constructs the space of possibilities within which form emerges through logical-computational derivation [2]. IM compels the designer to express form as a network of relationships: each entity is defined by topological dependencies,

metric constraints, continuity conditions and transformation rules. The project is no longer a manual act of creation but a dynamic system in which every local modification propagates coherent effects throughout the whole. Drawing thus becomes a responsive device that retains the memory of its own making [Kolarevic 2016, p. 26]. This reconceptualization of drawing coincides with the adoption of VPL (Visual Programming Language) and TPL (Text-based Programming Language), which enable a dual cognitive operation: on the one hand, the graphical-nodal reading of processes, useful for communicating and monitoring the operative chain at a glance; on the other, algorithmic writing, capable of formalizing functions, loops, conditions and of accessing the computational resources of the digital model in a precise and structured way.
Within this ecosystem of tools, models are not final products but intermediate states within a continuum. The process moves from the conceptual model, which captures intuition and requirements, to the study model, which explores constructive principles and materials; to the continuous model, which ensures the mathematical regularity of curves and surfaces; to the procedural model, which encapsulates instructions and parameters; to the fabrication model, which integrates metadata on materials, joints, tolerances, and strategies of cutting and assembly; and finally to the physical model, which verifies in the real world the coherence of the entire process [Calvano, Cognoli 2024, p. 177; Calvano, Mancini 2021, p. 3]. What ultimately matters is not the individual instance, but the informational continuity among states, the traceability of decisions and the capacity to recalibrate governing rules whenever performance, economic, or contextual requirements change.

The optimization of free form geometry

The management of free form geometry is the domain in which this framework reveals its full efficacy: non-canonical surfaces, high-order continuity, variable curvature, developable or quasi-developable panel subdivisions, discretizations, isogrid panelization logics, the rationalization of joints to simplify fabrication and assembly. The visible logic of algorithmic drawing enables these phases to be connected within a controlled flow, where complexity is not eliminated but made governable through explicit parameters and multi-objective optimization criteria [Carpo 2017]. At an operational level, IM enables strategies for exploring the solution space that combine local and global search methods. Parametric domains are defined by geometric constraints (G1/G2 continuity, curvature thresholds, minimum bending radii), by construction requirements (material thickness, sheet dimensions, CNC tool approach angles, printing speeds and layer heights for additive manufacturing), and by environmental and performance conditions (solar exposure, comfort, ventilation, structural behavior). On this basis, iterative loops of simulation, analysis, and selection are activated, producing not univocal but navigated solutions, in which the designer acts as the director of a process that makes the consequences of each choice transparent [Reichert et al. 2014, p. 33]. The algorithmic dimension, far from reducing expressive freedom, generates a conscious freedom, as it makes the trade-offs among alternative options explicit and allows for the measurement of how even minimal variations affect performance and feasibility. Visible logic thus manifests itself in the graph of relationships, in the taxonomy of parameters, in test reports and in color maps visualizing curvature, stresses, or deviations between the ideal model and its fabricable discretization. Within this scenario, the integration with Artificial Intelligence (AI) becomes particularly significant. NPL (Natural Language Processing) tools and conversational systems introduce a third linguistic layer, alongside VPL and TPL, that allows for the transition from description in natural language to the generation of executable code, or for querying the model to obtain explanations of its transformations [Wong et al. 2023, p. 2]. Drawing, understood as the act of defining rules, becomes both translatable and inspectable, while AI functions as a mediator between design gesture and computational formalization, accelerating iteration and facilitating dialogue between design and computational expertise. The impact is not merely instrumental but cognitive: a circular dialogue is established between intuition and calculation, between tacit and explicit knowledge, in which the articulation of each step becomes itself an act of construction. In this perspective, 'visible logic' also implies an ethical horizon of design transparency, where decisions are traceable and reasoned.
The production of the fabrication model represents a crucial testing ground: here IM intersects with manufacturing and construction disciplines, where the quality of drawing as construction is measured by the robustness of the transition from digital to physical (fig. 1). This entails embedding within the model not only geometries but production semantics (operational sequences, nesting and unrolling strategies for developable surfaces, printing parameters, data on reversible joints or tolerances) while verifying in advance collisions, protrusions, and assembly or maintenance accessibility. The model, in other words, is not merely the form but its constructive program, and its effectiveness is reflected in reduced waste,

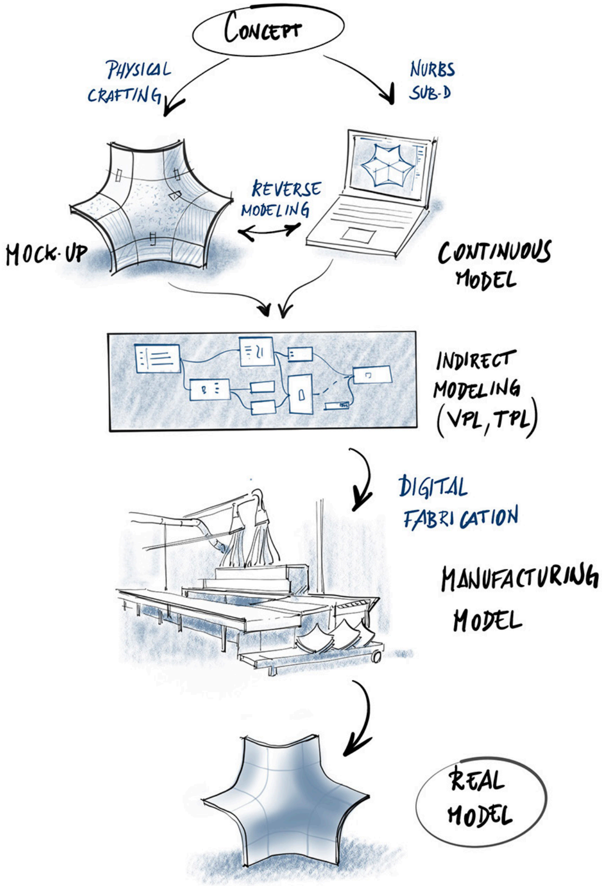


Fig. 1. Diagram of the modeling and form-construction process, from concept to realization (elaboration by the authors).

simplified workflows, and greater predictability of time and cost. The multiscalar dimension is intrinsic to this approach: the same logics apply across the scales of design objects, architectural components, envelopes, or installations, modulating the relative weight of parameters. Within this framework, the theme of drawing as construction acquires a new nuance: to construct means not only to fabricate, but also to equip thought and action with control structures that allow form to preserve identity through variation. Construction thus becomes a custody of invariant identity under transformation, and algorithmic drawing the tool that renders this custody measurable and verifiable.

The convergence of IM, VPL/TPL, and AI also enables a renewed relationship between geometry and meaning. Structure is not merely a technical fact but a symbolic principle that organizes the project and grounds its intelligibility. To make structure visible through drawing therefore means to restore to representation an active role in generating meaning, clarifying hierarchies, establishing priorities between performance and figuration, efficiency and expressiveness [Tedeschi 2014, p. 22]. From this perspective, algorithmic drawing is never a mere illustration but a form of argumentation: it demonstrates why a solution stands, why a detail works, and how a local variation affects global behavior. Since free form geometry naturally tends to conceal its constructive logic beneath the continuity of its envelope, the act of making its dependencies explicit becomes, in itself, an act of revelation.

Operationally, this translates into practices such as decomposing surfaces into portions of developable panels to reduce torsion and cost, aligning joints with principal curvature lines to improve structural efficiency, optimizing structural meshes through curvature gradients, calibrating minimum radii according to material bending limits or using SubD modeling to generate smooth transitions and subsequently converting them into controlled NURBS or mesh models for fabrication [Pottmann et al. 2007, pp. 601-606]. At the same time, verification protocols are implemented that, at each iteration, compare the model against acceptable deviation thresholds, generate non-conformity reports, and suggest corrective actions. The project thus becomes a continuous testing environment, where error is not waste, but information reintegrated into the system's learning cycle [Reichert et al. 2014, p. 36]. The adoption of data-driven practices, made accessible even to those without advanced programming skills through conversational interfaces, enables formal decisions to be correlated with measurable evidence and within this connection between evidence and form lies the profound nature of visible logic.

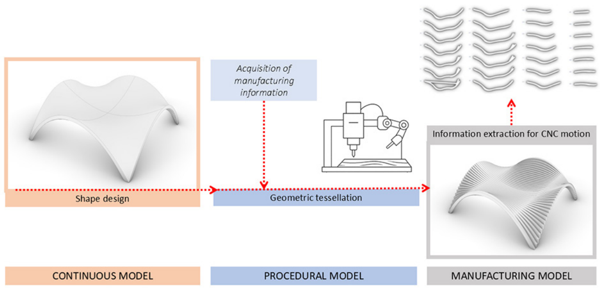


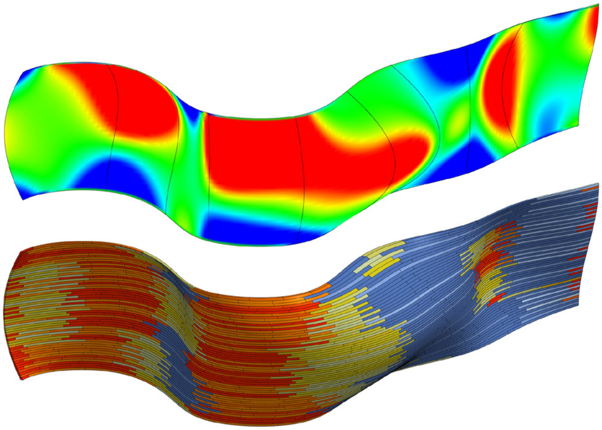
Fig. 2. Conceptual diagram of the algorithm enabling the fabrication of a continuous model through discretization into parts (elaboration by the authors).

If the first part of this discussion outlined the theoretical framework and operational structure, the next step is to demonstrate how these principles translate into concrete action. The following case studies serve precisely this demonstrative function: to test 'drawing as construction' in different contexts, examining how IM mediates between idea and feasibility, how VPL/TPL tools make design choices traceable, and how AI integration accelerates iteration and expands exploratory capacity. In these studies, the visible logic of drawing will serve as a guiding thread: structure will emerge as an organizing principle before it becomes a formal outcome, and the algorithmic device will render legible a grammar often implicit in the finished result. Specifically, they aim to illustrate in detail how the methodology based on the sequence of models (conceptual, continuous, exploratory, procedural, fabrication, and physical) can be translated into both design and construction applications (fig. 2). Each experience was developed in distinct contexts, revealing the breadth of possibilities afforded by algorithmic drawing. The value of these experiments lies not only in their tangible results (complex furniture, parametric façades, free form cladding) but also in the opportunity to observe how algorithmic logic imparts coherence, efficiency, and adaptability to processes. The objective is twofold: first, to demonstrate the recursiveness of a method capable of traversing different scales and domains while maintaining its operative structure; and second, to verify an epistemological assumption that drawing, when algorithmic and responsive, does not merely communicate form but constructs it. And precisely because it constructs it, it renders it intelligible and shareable; in short, it makes it a visible logic.

Experimental cases: applications of algorithmic drawing

The first case concerns the development of the wooden furniture for the lounge bar and restaurant of the Oasis Skyview Hotel in Doha, an environment that challenged the designers to reconcile an organic, enveloping form with the rigor expected in a high-end representational setting. The client, aiming for a design that evoked both elegance and fluidity, required the use of solid wood, a material that guarantees aesthetic quality but imposes significant manufacturing constraints (fig. 3).
To address these challenges, a methodology based on the coordinated use of digital and physical models was adopted. The conceptual model played a generative role: through SubD and NURBS modeling, multiple formal variants were explored in a short time, and the aesthetic quality of curved surfaces was assessed. This intuitive free-form phase was followed by the continuous model, obtained through reverse modeling operations, which corrected topological discontinuities and ensured the geometric continuity of the surfaces. The solidity of the digital model enabled an efficient transition to subsequent stages (figs. 4, 5).
In parallel, the physical study model proved fundamental. Through the production of *maquettes* and partial prototypes, the designers verified the feasibility of solutions, tested assembly methods, and identified the dimensional constraints imposed by wooden panels. Direct experimentation with materials provided essential data for structuring the procedural model, which translated the acquired knowledge into a set of algorithmic rules capable of automating surface discretization into planks, optimizing nesting, and introducing constraints consistent with CNC

Fig. 3. Experimental mock-up for investigating the materials and technologies to be used in the construction of the final architectural element (photos: Devoto Design).



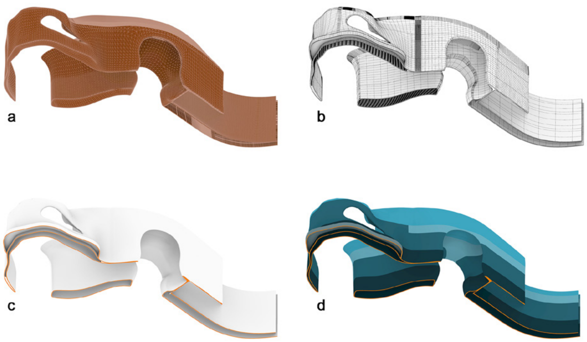


Fig. 4. Tessellation of the complex form in relation to the curvature parameter: greater curvature corresponds to shorter tiles; lower curvature to longer ones [Calvano, Mancini 2020, p. 112].

Fig. 5. Models derived from the topological optimization process of the form, preparatory to the tessellation stage [Calvano, Mancini 2020, p. 109].

fabrication technologies (fig. 6). The fabrication model integrated geometric and textual data, along with alphanumeric codes required to drive machines and ensure component traceability. The real model (the installation of the double-curved wooden walls) validated the approach: not only was the complex form successfully realized, but the process also reduced errors and production times. This case exemplifies how the concept of 'simplexity', simplicity governing complexity, can serve as an effective operational principle.
The second case belongs to the field of architectural research and focuses on the design and fabrication of complex wooden façades, emphasizing the relationship among parameters, constraints and robotic techniques. The objective was not only to give form to an innovative envelope but also to demonstrate how algorithmic drawing could guide the translation of geometric relations into automated construction processes. The conceptual model functioned as an experimental space, in which different configurations were explored to optimize summer shading through data-driven logics. From this initial stage emerged the definition of critical parameters such as the orientation and density of wooden elements.
Subsequent study models, realized as physical prototypes, enabled testing of materials, assembly strategies, and structural constraints, providing tangible feedback on constructability. The transition to the continuous model ensured geometric coherence, resolving topological issues and preparing the ground for the algorithmic phase. The procedural model, implemented through VPL, made explicit the relationships among element density, assembly clusters and fabrication parameters (fig. 7). At

Fig. 6. Stages in the production of panels used to mill the wooden tiles for constructing a physical model of a complex form (photos: Devoto Design).

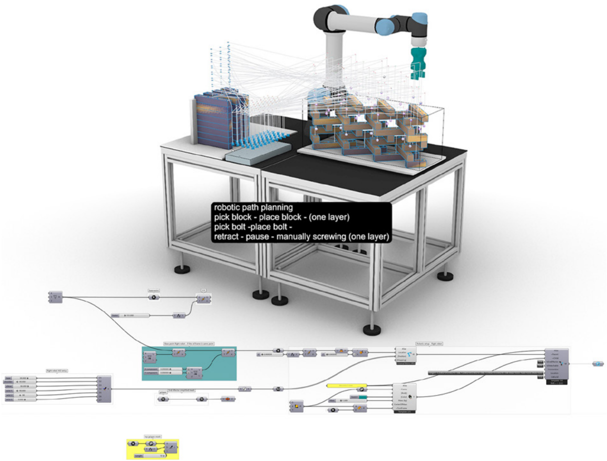


Fig. 7. Simulation of the robot-assisted construction process. Assembly parameters controlled through the use of VPL [Cognoli 2024, p. 284].

this level, manual experiences were codified into rules, translating craft-based knowledge into machine-executable sequences. The fabrication model integrated these datasets, specifying tolerances, CNC toolpaths, and trajectories for collaborative robots. Finally, the real model, assembled through robotic fabrication, validated the chain of models, demonstrating the capacity to manage complex structures with high precision and repeatability. An additional outcome was the integration of digital twin systems, enabling continuous feedback between representation and reality through real-time data on the behavior of the built object.
The third case illustrates the effectiveness of technological transfer between academic research and industrial practice, realized through the design of the cladding for a free form helical staircase (fig. 8). Collaboration with an interior-contracting company [3] enabled the application of experimental methodologies in a real production context, facing stringent economic and temporal constraints. The design task, a custom interior staircase composed of approximately 1000 coded components made of different materials (MDF, birch plywood, solid ash, veneer), required an integrated workflow to coordinate design and fabrication.

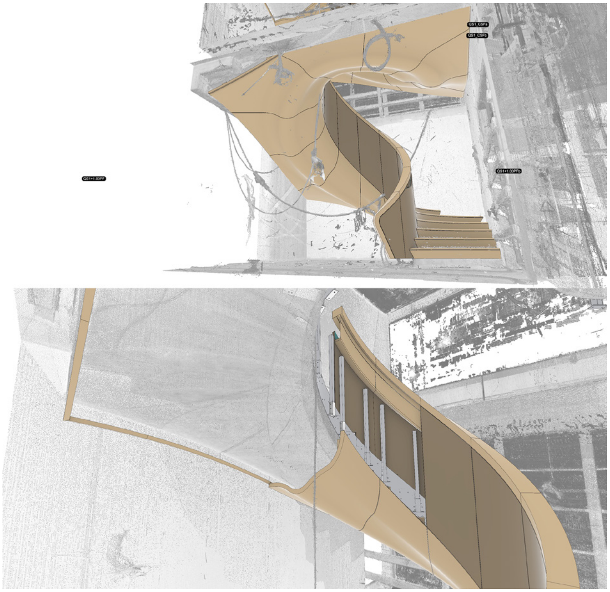


Fig. 8. Construction phases of the free form staircase. On-site installation and assembly of prefabricated modules manufactured in the workshop (photos: Devoto Design).

Fig. 9. Interference check between the point cloud representing the concrete staircase and the fabrication model of the designed wooden cladding (model by Michele Calvano and Roberto Cognoli).

The digital study model served to validate formal choices, simulate assembly constraints, and test materials. The continuous model corrected topological inconsistencies and established a coherent geometric basis for subsequent parametric phases. The procedural model, implemented in VPL, introduced dynamic management of geometric and constructive parameters, enabling real-time updates and embedding control logics for connections. The fabrication model translated this information into operational instructions for CNC and robotic tools, optimizing nesting processes and reducing material waste by 30% (fig. 9). Furthermore, component coding allowed full traceability and the management of a digital database useful for maintenance and reuse. The real model, assembled and installed in 20% less time than standard benchmarks, confirmed the workflow's effectiveness, while the experience consolidated the capacity to transfer academic know-how into replicable industrial practices. This case confirms that algorithmic drawing can act as a bridge between research and production, strengthening the sustainability and competitiveness of small and medium industries.

Conclusions and future developments

Direct comparison among the case studies reveals the coherence and flexibility of the sequential model methodology. Despite the diversity of contexts, from luxury furniture to architectural façades and industrial contract work, the structure of progression remains consistent: from conceptual to real through the algorithmic filter. In each case, algorithmic drawing not only made the internal logic of form visible but also organized it into constructive rules. The added value lies in the ability to integrate aesthetic, technical, and informational dimensions within a unified process that finds its most effective language in parametric representation. Visual and textual programming environments, now complemented by AI-driven linguistic interfaces, reinforce this perspective by ensuring traceability and continuous control. Looking forward, the integration of artificial intelligence and digital twin systems appears as the natural evolution of this approach: the former capable of translating natural language into computational code, the latter providing continuous feedback from the physical to the digital realm. Beyond these operational functions, AI introduces a novel dimension: the possibility of embedding lateral thinking within design processes. On the one hand, AI can overcome specific technical limitations, automating complex computational tasks; on the other, it can propose radically different solutions from those a human designer might conceive following linear or discipline-bound reasoning. In this sense, the contribution of AI does not merely enhance efficiency or optimize workflows, it transforms the very perspective from which problems are approached, fostering the emergence of alternative viewpoints and unexpected configurations. This paradigm shift positions AI not simply as a support tool but as a potential co-author in design, capable of introducing new modes of creative exploration that enrich and expand the disciplinary horizon.

Credits

Although the work is the result of full conceptual and methodological sharing among all the authors, the following individual contributions can be identified: Leonardo Baglioni authored the introductory sections, focusing on the constructive nature of Descriptive Geometry and its underlying theoretical foundations; Graziano Mario Valenti developed and refined the methodologies of algorithmic drawing, with particular attention to the formalization of indirect modeling and procedural logics; Michele Calvano conducted the practical experiments, contributing to the methodological and procedural implementation and directly overseeing the fabrication processes involved in the case studies. This distribution of contributions reflects the complementarity of expertise and the synergistic collaboration that characterized the entire work.

Notes

[1] This contribution gathers ideas, reflections, and experiences developed within the Research Unit 'ForMaRe' (Form design, Manufacturing & Research)'', recently established in the Rome area. The Research Unit was founded with the aim of investigating, both theoretically and practically, the processes related to form, understood as the dynamic and complex outcome of a trajectory encompassing conception, modeling, verification, and fabrication. From this perspective, form is conceived as the result of continuous interaction between design thinking, geometric theories and tools, and technological supports, within a constant dialogue between conception and realization: <https://dsdra.web.uniroma1.it/it/unita-di-ricerca-sulla-forma> (accessed 3 July 2025).

[2] The term 'Indirect Modeling' refers to the process of transcribing and formalizing operational and algorithmic logics within a digital environment through the use of programming languages. Such languages make it possible to explicitly structure the relationship between data and operations, rendering transparent the procedural sequence that leads to the elaboration of the model. In this perspective, modeling is not understood solely as a means of production but as a descriptive and meta-reflective practice capable of revealing the dynamics of the design process itself. Consequently, it becomes possible to configure a new form of "digital *ékphrasis*, similar to that of Renaissance treatises, that describes the process even before the final product" thereby assigning to the model a heuristic as well as a representational value [Valenti 2021, pp. 133-135].

[3] Engagement with industrial partners, such as the collaboration initiated with Devoto Design, a company specialized in digital fabrication and in the realization of projects featuring geometric and organic surfaces, does not merely constitute a one-way transfer of knowledge. On the contrary, the production context itself often stimulates new questions, generates original research insights, and fosters critical perspectives that would hardly emerge within the academic environment. In this sense, such collaborations represent a concrete opportunity for dialogue with the operative realities of architecture and design: <https://www.devotodesign.it/it/> (accessed 18 June 2025).

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Fractal Structures. Understanding the Geometries of Nature

Michela Rossi, Giorgio Buratti, Andrea Rossi

Abstract

The observation of nature has historically guided design disciplines, from the proportional harmony of antiquity to the empirical studies of the Renaissance, which laid the groundwork for the development of biology and bionics. In the 20th century, the formulation of fractal geometry and the emergence of computer science made it possible to describe and simulate complex systems, going beyond formal imitation to investigate the processes of growth, adaptation and self-organisation characteristics of living organisms. Mandelbrot's research has enabled the quantitative interpretation of morphogenetic phenomena in the natural world, highlighting fractal rules common to both animal and plant systems. The history of architecture is full of examples of the unconscious adoption of self-similar logic, which can now be reinterpreted using algorithmic and parametric modelling tools. This article proposes a reinterpretation of organic models and construction archetypes, such as brick, within a design paradigm based on computational morphogenesis, in which natural principles are transformed into operational protocols capable of combining formal complexity, structural efficiency and construction innovation.

Keywords: computational morphogenesis, fractal geometry, computational design, brick, construction archetypes.

Introduction

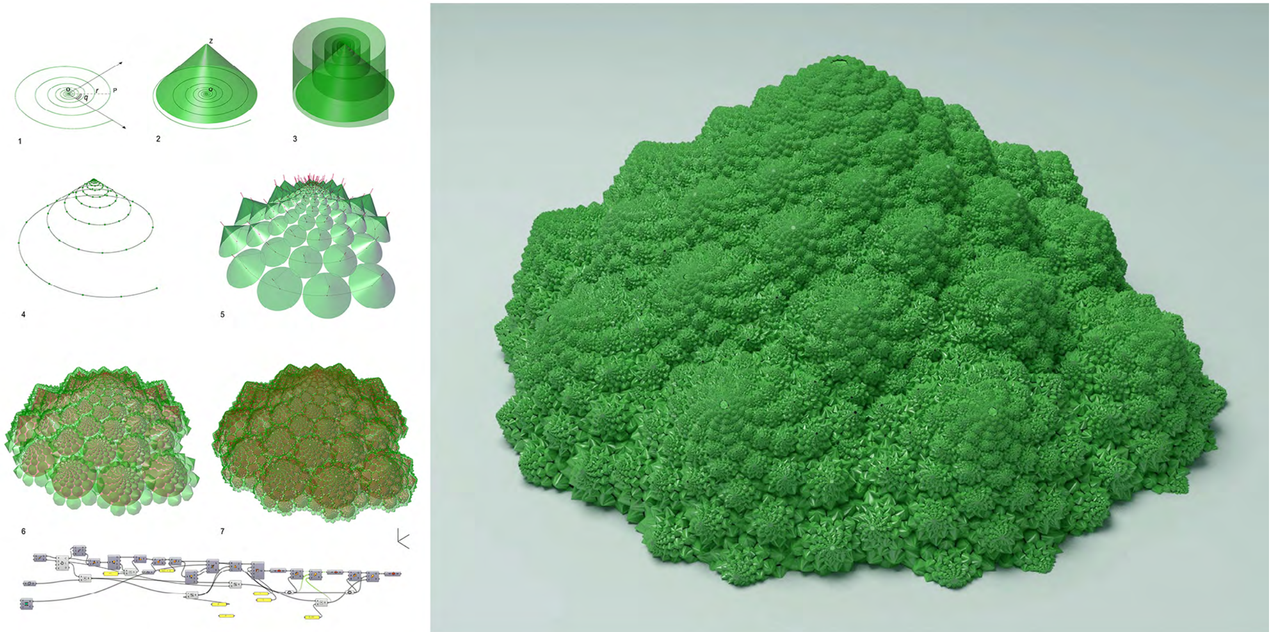
Nelle discipline progettuali, l'analisi sistematica e la comprensIn design disciplines, systematic analysis and understanding of morphological structures play a crucial role in ensuring the efficiency of the proposed solutions. The outcome of any design process is, in fact, conditioned by the ability to meet operational requirements such as time constraints, material resources and manufacturing processes necessary to achieve the set objectives. Since a large part of human learning takes place through imitation, it is not surprising that the natural world has historically been the primary source of inspiration [Rossi 2001; Rossi 2006]. Since the earliest manifestations of graphic representations of natural organisms and phenomena –such as those found in cave paintings– humans have studied nature to decipher its principles. In classical antiquity, the observation of biological models was primarily aimed at translating the harmony of natural forms into mathematical and numerical language through the study of proportional relationships between different morphological components. These investigations not only guided the aesthetic canons of art and architecture but also laid the foundations for an initial formalisation of structural correspondences. It was only with Leonardo da Vinci's Renaissance studies on the flight of birds, perhaps the first documented example of research supported by a systematic analysis of a biological system, that the connection between natural phenomena and design processes began to promote an empirical approach. However, the

ability to translate natural principles into applied technologies remained fragmented, determined by the level of development of the theoretical tools and technologies available. Although there were erratic cases of earlier applications, it was only at the beginning of the 19th century, with the advent of biology as an autonomous discipline dedicated to the study of living systems, that the relationship between design and the natural world acquired a rigorous methodological basis [Thompson D'Arcy 1917]. During the 20th century, the emergence of biotechnology in the first half and bionics in the second half led to the development of cognitive models capable of describing more complex relationships and dimensional realities in mathematical terms. This made it possible to reproduce and control biological structures and phenomena that were once thought to be undisputable. With the new millennium, the organic reference took on considerable importance in the progressive shift of interest from form to the relationships constituting generative dynamics, in an in-depth study that led over time to the replacement of mere imitation with the analysis of biological processes of growth, transformation, and responsive adaptation [Rossi 2014; Rossi 2019; Rossi, Buratti 2017].
In the field of design practice, this progress can be attributed to two distinct yet related factors. The first is the formulation and characterisation of Mandelbrot's fractal geometry, influenced by a broader epistemological shift that sees the abandonment of the classical deterministic paradigm in favour of studying the intrinsic non-linearity of natural phenomena.
The establishment of computer science represents the second factor as an autonomous scientific discipline, utilising computers not only as a calculation tool but also as a privileged means for investigating, modelling, and simulating design systems based on complex logic.

Fractal geometry: references and digital models

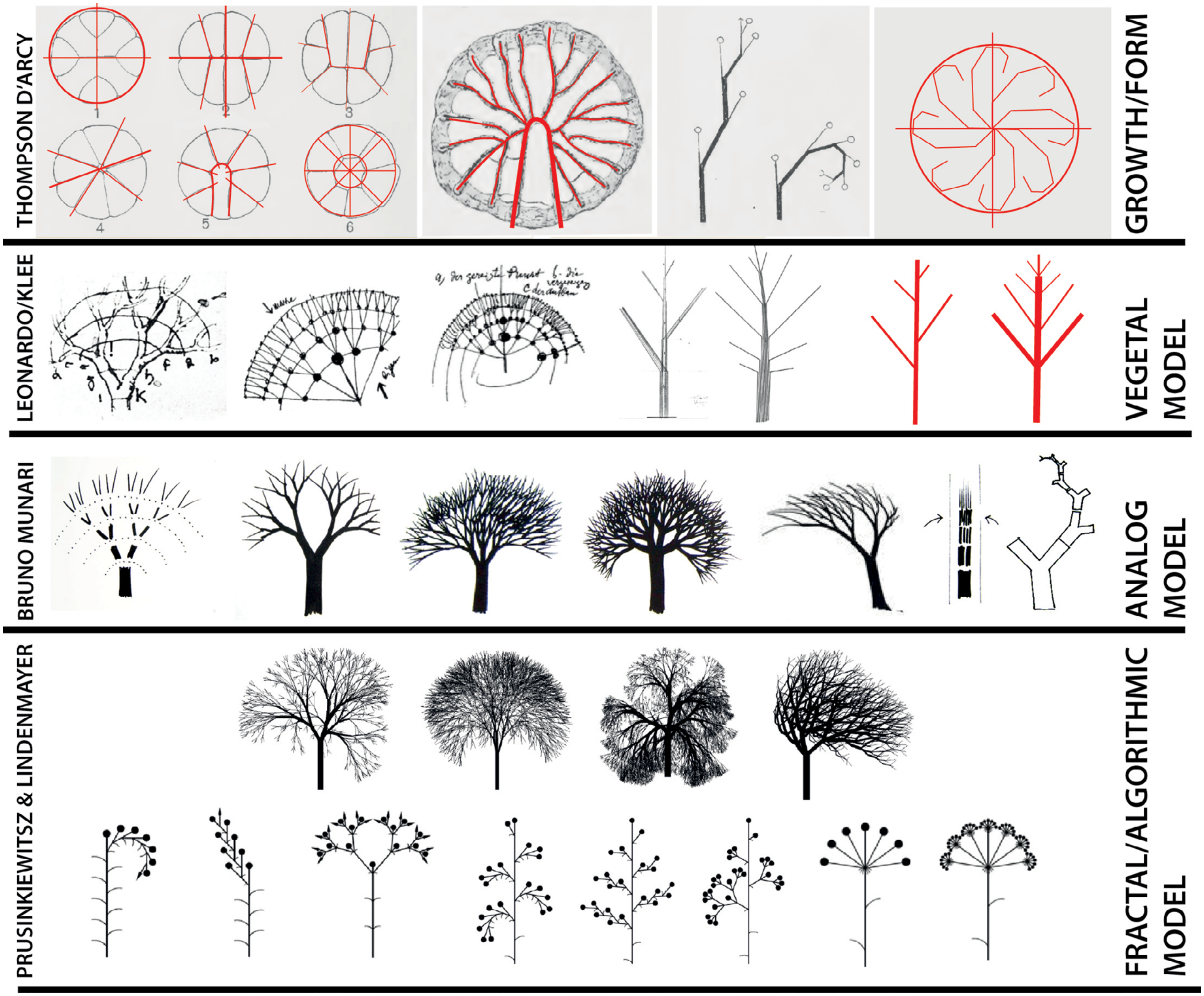
Fractal geometry has made it possible to describe and quantitatively characterise complex natural structures that are too intricate to be defined in Euclidean terms. Strictly speaking, fractal models can be recognised in numerous artistic and architectural expressions that developed across centuries and continents, even before Mandelbrot's studies [Mandelbrot 1975]. Traces of self-similar geometries can be found in classical Greek art and African vernacular architecture, in the decorations of Egyptian civilisations, in pre-Columbian cultures, as well as in Islamic and Hindu religious complexes [Sala, Cappellato 2004]. They reflect the aforementioned predisposition of human beings to reproduce in construction and decoration the same principles of complexity and self-organisation observable in natural ecosystems, characterised by sensorially rich patterns, spaces connected on multiple levels of scale, and fractal dynamics of repetition and continuous variation.
It is also true that, from a scientific perspective, fractal structures were already known by the end of the 19th century and in the early decades of the 20th century. Georg Cantor (Cantor set, 1883), Giuseppe Peano (Peano curve, 1890), David Hilbert (Hilbert curve, 1891), Helge von Koch (Koch snowflake, 1904) and Wacław Sierpiński (Sierpiński carpet, 1916) had described sets and curves that challenged classical Euclidean notions of topological dimension, Lebesgue measure [1] and perimeter. These objects were united not only by recursive iteration, internal homothety and self-similarity, but also by the impossibility of being represented as the locus of the solution points of differential equations or elementary algebraic-geometric systems. Paradoxical properties such as curves of infinite length delimiting regions of finite area or disconnected but not discontinuous sets caused scepticism and mistrust among many scholars of the time, so much so that fractals were initially considered 'mathematical monsters' [2] with no counterpart in physical reality [Falconer 2003]. It is therefore thanks to Mandelbrot that these objects find an actual correspondence in the real world, even if the fractal structures observable in nature exhibit self-similar behaviour only within a defined interval. This is because, as Goethe already intuited when he said that 'nature has ensured that trees do not grow to the sky' [3], natural laws vary according to the phenomena considered. For example, at the cellular level, where the growth of living organisms is concerned, the force of gravity does not play a decisive role. In contrast, in the macroscopic world, this force profoundly affects the structure and movement of bodies. Even the arrangement of plant organs according to phyllotaxis patterns responds to a morphogenetic organisation that optimises exposure to sunlight and air circulation, ensuring physiological conditions conducive to growth. A prime example is Romanesco broccoli, frequently cited for its extraordinary geometric regularity

Fig. 1. Morphogenetic development of Roman broccoli (elaboration by the authors).



and the marked recursiveness of its structures, characteristics that make it easy to model algorithmically (fig. 1). The same logic of efficiency in the spatial distribution of branches can also be found in the morphological development of numerous tree species. It is therefore not surprising that, in the field of design, references to the organic world have taken on an increasingly important role over the years, in parallel with a shift in interest from form to the complex generative dynamics that underlie it. This in-depth study has gradually led to the imitative approach being overcome, directing research toward the analysis of growth, combination, and structural processes. One of the first examples of the conscious application of biomechanical principles in architecture is the Crystal Palace, built in London in 1851 for the Great Exhibition, also known as the first World's Fair. The design, conceived by Joseph Paxton, reinterprets *Victoria Amazonica* [4] in the design of the iron supporting elements of the building's roof arches, allowing for the creation of a highly lightweight structure that is nevertheless capable of supporting large glass surfaces. The organic metaphor also influenced American architectural thinking, particularly through the theories of Horatio Greenough, who identified the correspondence between form and function as a fundamental principle of natural organisation [Greenough 1975; Greenough 1852; Tuckermann 1853].The form is shaped in response to the functional needs of the genus and species, through a process of adaptation that reflects the natural formal economy. These concepts found effective synthesis in Louis Sullivan's famous motto, *form ever follows function*, which formulated a principle that was to exert a profound influence on 20th-century architecture and design, constituting one of the theoretical foundations of the Modern Movement.
During the same period, Eugène Viollet-le-Duc produced drawings that 'rationalised' the conformation of mountains [Viollet-le-Duc 1876] and glaciers, considered by analogy as ruined buildings in need of restoration. The French architect described the heights with a geometrisation that anticipated the principle of box counting associated with IFS (Iterated Function System) fractals, a solution he considered necessary to overcome the limitations of Euclidean geometry in the description of natural phenomena, anticipating Mandelbrot by almost a century with his functional fractal generation for the digital modelling of the orography of territories. The characteristics of self-similarity and scale invariance lend themselves to the creation of efficient algorithms that enable the development of predictive simulations of complex systems, territories, or organisms.
In this regard, it is particularly interesting to compare this method with the one proposed by Bruno Munari for graphically representing a tree, through a process that aims to understand its genesis and formal logic. The exercise involves constructing a simplified model [Munari 1978] which, although designed for educational purposes, serves as an effective analogy of an IFS (Iterated Function System) fractal structure, generated according to a deterministic algorithm [Sala, Cappellato 2004]. Although Munari does not explicitly refer to fractal mathematics, the association has been evident since 1990, when Hungarian biologist Aristid Lindenmayer and Polish computer scientist Przemysław Prusinkiewicz published the first systematic study on the digital simulation of plant morphogenesis. In this research, *L-system* –generative formalisms introduced by Lindenmayer himself in 1968– were applied to model plant growth patterns [Prusinkiewicz, Lindenmayer 1990]. The logic of generating tree morphology and annotating how external factors –primarily the action of wind– can modify development with respect to the 'ideal' growth model is the same. The analogy between Munari's drawing of a tree bent by the wind [1978] and the morphological deformation scheme subsequently published by Prusinkiewicz and Lindenmayer is particularly evident: in both cases, there is a systemic deviation of the geometries derived from environmental inputs, which corresponds to the generative computational models of *L-Systems* (fig. 2). The designer cites the source in his own way: "An old friend of mine from the provinces, a certain Leonardo, born in a small village near Florence: Vinci (postcode 50059) was an inquisitive man. He would spend hours observing plants and then drawing them and noting down everything he could understand about how they branch out" [5].
The representation reveals the growth rules that constitute the compositional pattern of the design and digital modelling. Thus, interest in fractals extends to the fields of design and architecture, and even to spatial planning, an area in which design is called upon to bring order to a complex and apparently chaotic system, in which the signs of anthropogenic transformations have become stratified [Rossi et al. 2022]. C. Alexander's Pattern Language emphasises the relationship between the fractal

Fig. 2. Evolution of growth and branching models: from D'Arcy Thompson's morphological growth model to L-system fractal models (elaboration by the authors).



geometry of *L-Systems* in settlements and territorial configurations that show the development of self-similar structures in the hierarchical aggregation of the archetype of housing as a large-scale design method, aimed at ensuring a balanced development between the different needs of a complex society [Alexander et al. 1987; Sala, Cappellato 2004].
A reference to the self-similarity of fractals can also be found in the rationality of medieval buildings. One example is the diverse decorative and construction solutions of the large rose windows in medieval cathedrals, which follow a combinatorial logic, as seen in Milan Cathedral [Rossi, Buratti 2022], another artificial representation of the cosmos.
Once again, once a new mathematical approach has been defined to solve an unsolved problem, its effectiveness in relation to other issues is discovered with the development of simplified solutions, consistent with the latest digital design tools. In recent decades, fractal models have acquired a fundamental role in modelling various scientific fields, including biology, economics, and the social sciences, as well as medicine, with constantly growing fields of application. Fractals, therefore, offer significant potential for the development of digital applications geared towards architectural design on all scales. This article presents some experiments aimed at morphological optimisation, seeking to reinterpret formal archetypes and historical patterns in a contemporary key, using computational tools capable of integrating geometric complexity and structural coherence.

Designing complex fractal structures: from broccoli to rose windows

The characterisation of fractals is not based on a single analytical expression, but on an algorithmic process (not necessarily numerical in nature) used to generate a surface curve. An algorithm is a systematic protocol consisting of a sequence of formally defined and unambiguously interpretable instructions, designed to guide an executing agent toward achieving a predetermined goal. When that agent is an electronic computer, the algorithm must be coded in an executable programming language.
As already mentioned, computer science has played a fundamental role in the study of fractals. Thanks to computers, Mandelbrot was able to simulate the complexity of the recursive laws typical of nonlinear systems, discovering the rules that govern their evolution a posteriori. In this way, he demonstrated that such phenomena cannot be treated with a top-down hypothetical-deductive approach, i.e. by predicting future trends based on initial conditions, but require a bottom-up model. By defining the behaviour of individual elementary entities and exploiting computing power to simulate their collective interactions, it is therefore possible to highlight recurring patterns and compare them with natural processes.
The refinement of IT skills that characterises the new millennium has also led designers to explore the processes hidden by the interface that determine the functioning of everyday digital tools. This focus has promoted the evolution of a new type of computer-aided design, which frees designers from the restrictions imposed by traditional modelling software, thanks to the possibility of defining the process of relationships that lead to the formation of the shape itself. The morphology of an artefact thus becomes the result of the interaction between various design determinants, whether technological, economic or cultural, in a process defined as computational morphogenesis precisely because, as in the natural morphogenesis that characterises the development and growth processes of living organisms, form arises from the interaction of material capacities intrinsic to the system and exogenous environmental forces.
The examples presented in this work demonstrate how this approach enables the description and control of the complexity factors in the biological reference models.
Using *Grasshopper*, a visual algorithm editor associated with McNeel's *Rhino* software, various definitions were developed to describe organic morphologies precisely.
The first algorithm [Buratti, Rossi 2021] takes Romanesco broccoli as a reference, a vegetable that has attracted the interest of many scholars due to its peculiar self-similar morphology. The arrangement of the rosettes follows a fractal structure attributable to principles of internal homothety. Each inflorescence replicates the geometry of the whole on a smaller scale, generating an iterative sequence of cones arranged along the lateral surface of the previous one. This growth can be described using the Fibonacci sequence, whose successive ratios approximate the proportional invariance observed in the spatial distribution of the elements (fig. 2). In this way, the spatial distribution of the inflorescences is optimised, making the most of the ratio between the number and size of the

Fig. 3. a) Diagram of Pythagoras' fractal tree; b) Three-dimensional equivalent based on triangular prisms and tetrahedra; c, d) Comparison of the fractal development that governs the growth of a tree and also regulates the morphogenesis of pulmonary blood vessels (elaboration by the authors).

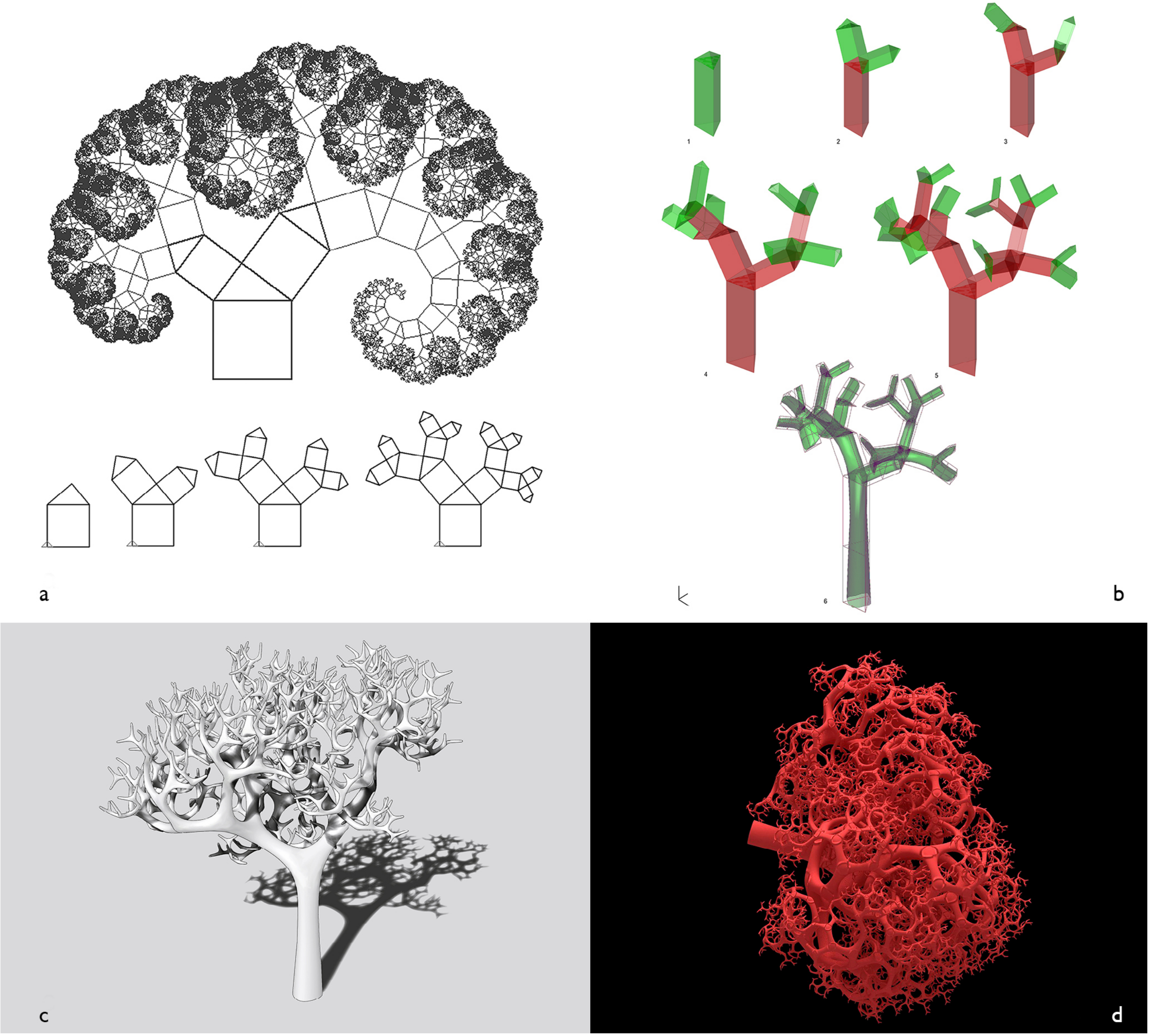
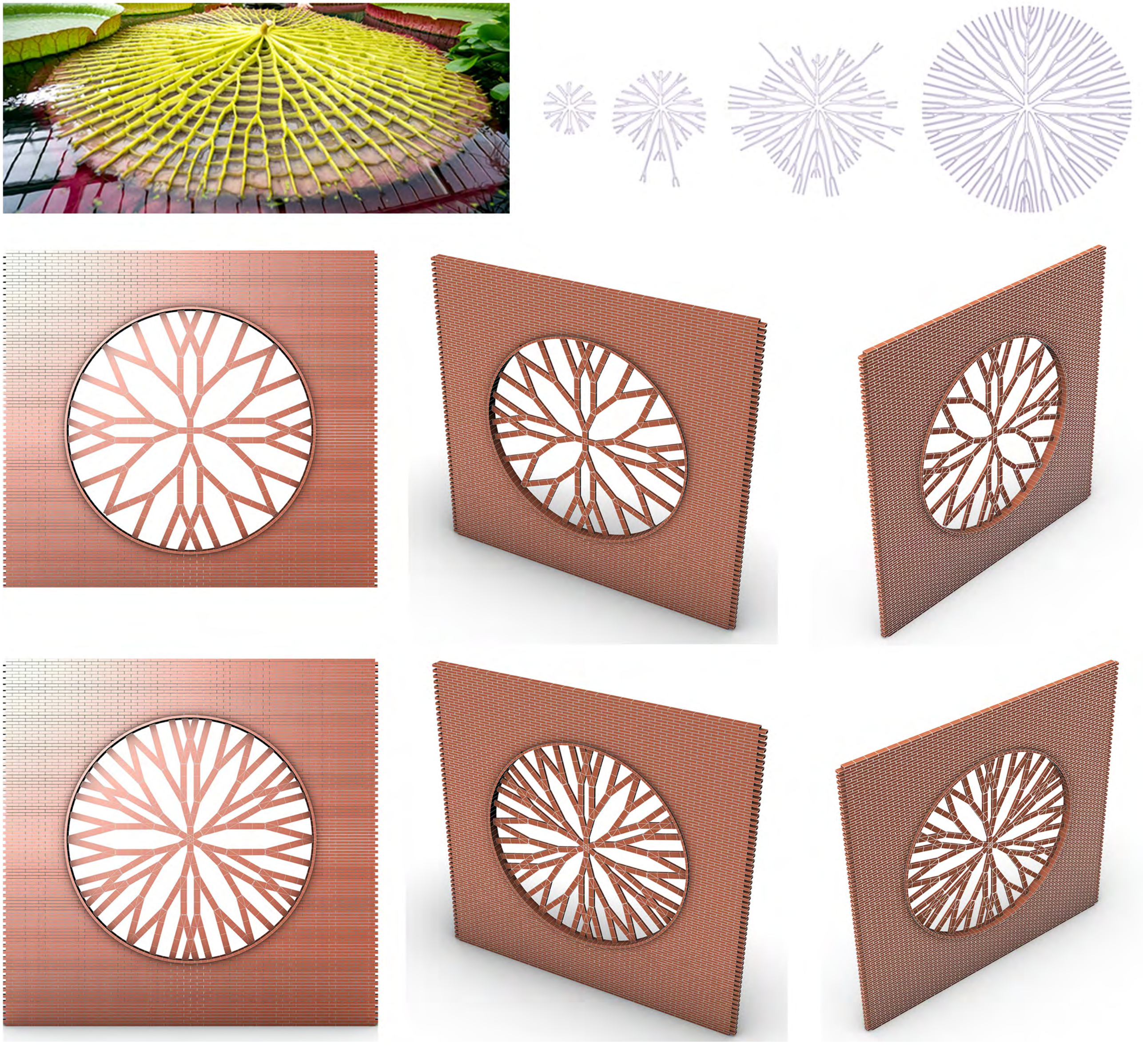


Fig. 4. Study of the morphogenetic process of Victoria Amazonica, characterised by radiant and branched growth that incorporates principles of structural efficiency and translates its radiant structure into ornamental building elements based on bricks (elaboration by the authors).



cones and the available surface area. One may wonder why Romanesco broccoli develops its heads from a circular base rather than other polygons capable of optimising the tessellation of the surface, such as squares, triangles or hexagons. One possible answer is that the curvature of the conical surface maximises exposure to sunlight, regardless of the angle of incidence, thereby increasing the efficiency of light absorption for photosynthesis, even in conditions of limited illumination [6].
The second algorithm [Buratti, Rossi 2021] computes three-dimensional branched structures inspired by the "Pythagorean tree" fractal (fig. 3a), based on the Pythagorean identity $a^2=b^2+c^2$ and a binary iterative process of rotations and homotheties. In three-dimensional space, the construction replaces squares and triangles with triangular prisms and tetrahedra (fig. 3b), generating self-similar geometries representative of plant branches and the pulmonary vascular system (fig. 3c, d). In this case, the repetition of the binary division, associated with the halving of the section, allows for effective occupation of space without interference between one branch and another. The reason for this is easy to understand when one considers how closely respiration and photosynthesis are linked to the efficiency of gas exchange. This increases as the available surface area increases, hence the branches, which, in the limited volume of the lungs, can generate surfaces of up to 100 m², the equivalent of a tennis court.
Subsequent experiments exploit the fractal properties of self-similarity and recursion in the modular use of bricks. Bricks are a fundamental building element whose history is intertwined with the development of architecture and civilisation. Its versatility, durability and ease of production have made it a preferred material in different ages and cultures, giving rise to a wide range of construction techniques and architectural styles that are not limited to simple masonry use but extend to the construction of vaults, arches and domes, demonstrating the flexibility and ability of brick to adapt and combine in complex geometries.
The iterative and recursive principles whereby, in a fractal, an elementary shape repeats itself according to scalable patterns, generating structures that nevertheless maintain geometric consistency, translate into constructional terms into compositional systems in which individual bricks, understood as fundamental units, are aggregated according to configurations typical of self-similar systems [Jong 2005]. The adoption of fractal patterns not only optimises the use of space but also the distribution of structural loads, thanks to their unique hierarchical and branched nature, which, as demonstrated by numerous examples in nature, promotes efficient stress transmission [Banach, Wrobel 2014]. Furthermore, the fractal dimension, a non-integer measure that quantifies geometric complexity, can guide modular design to maximise the contact surface and cohesion between individual elements, facilitating their possible digital fabrication [Oxman 2010].
In synergy, fractal principles and bricks were initially applied to possible configurations of rose windows, radial elements of ornamental and symbolic value, which lend themselves well to algorithmic reinterpretation [Buratti, Rossi 2022]. From a geometric point of view, in fact, a rose window can be constructed as a series of recursive transformations applied to a basic module (brick). Each iteration produces a reduced or rotated copy of the module, arranged according to radial symmetries belonging to dihedral groups D_n but enriched by scalar variations and translations on multiple scale levels (figs. 4, 5).
The algorithmic process defines the primitive unit –the brick– and its connection graph, described as a set of planes oriented in space that represent possible coupling interfaces. Translation and rotation operations applied to these planes modulate the topological and metric relationships between adjacent modules. The recursive application of these rules then generates complex discrete structures, similar to those produced by *L-System* generative systems.
A second series of studies explored the possibilities offered by introducing spatial hierarchies between elements, modifying the generation process and aggregation rules to construct structures based on a series of load-bearing arches and related infills.
The adoption of discrete computational design logic, formalised in the *Wasp* tool [7] [Rossi 2017; Rossi, Tessmann 2019], made it possible to tackle the complexity determined by the use of brick in a hemispherical dome and to study the possible variants (figs. 6, 7). Although the bottom-up approach allows for the exploration of a wide range of geometric configurations, the proposed algorithm does not compute indications on the stability of the final structure. The generation of the structure based solely on local relationships does not imply that the algorithm is efficient in considering the overall morphology of the whole. This lack of control at the

Fig. 5. Another structural scheme based on Victoria Amazonica for the design of an architectural element that highlights the transfer of organic branching principles into a functional geometric configuration for building construction (elaboration by the authors).

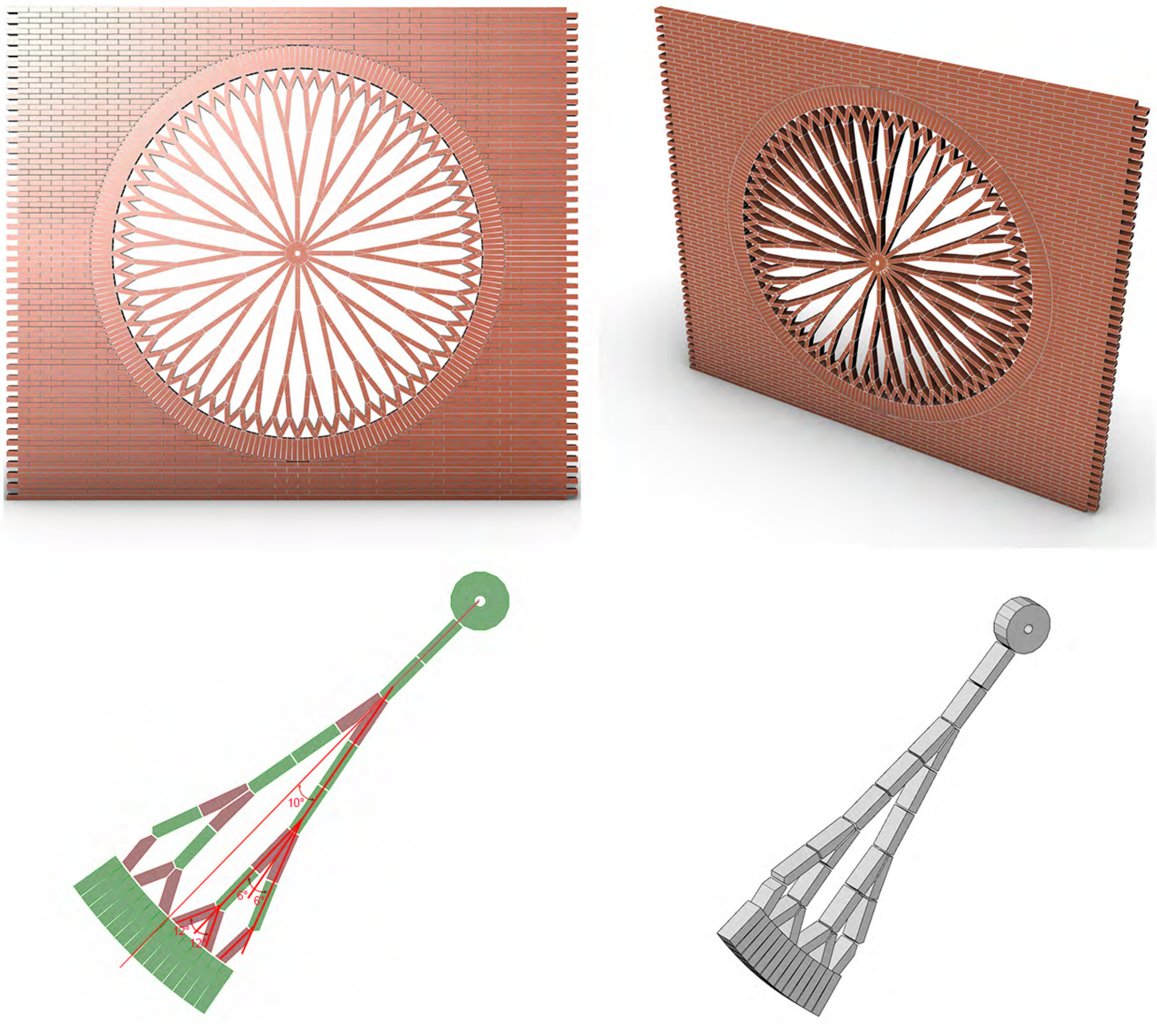
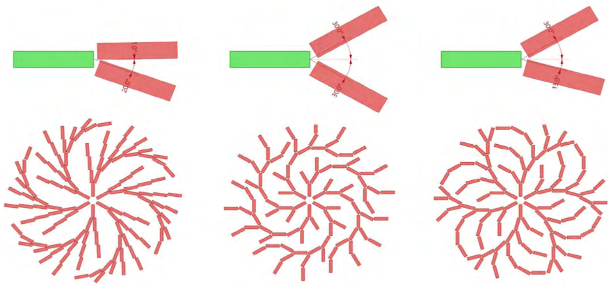
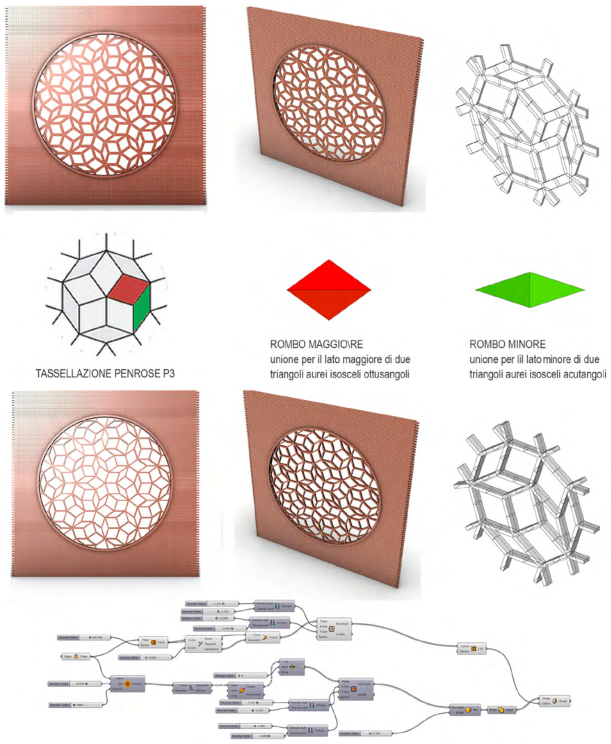


Fig. 6. Computational investigation of the application of organic growth models for structural design in architecture: transposition of biomimetic schemes for the construction of domes through the formal and structural optimisation of the use of brick (elaboration by the authors).

Fig. 7. Parametric relationships between the various brick elements (elaboration by the authors).

Fig. 8. Experimentation with the use of brick as a building module for the creation of a Penrose tiling. The synergy between aperiodic geometry applied to a traditional building system demonstrates the innovative potential of computational design (elaboration by the authors).





macro-structural level can lead to brick distributions and spacings that, while complying with local rules, are inadequate to ensure the overall stability conditions required by the construction system. To address these issues, a process initially developed for creating structures from irregular elements [Allner et al. 2020] has been adapted, utilising the physical simulation of the structure through the *Kangaroo* plug-in [Piker 2013]. Each brick is defined as a rigid body connected to adjacent bricks with variable resistance springs. When the physical solver is activated, the springs pull the bricks towards each other, optimising the spaces between them. By controlling the maximum distance at which two bricks are considered connected, it is possible to close spaces of varying sizes, thereby reducing the structural instability.
Further experiments will study new composition schemes (fig. 8) and constructions based on heterogeneous elements, characterised by variations in scale or geometric differences. This also includes irregular or partially deteriorated components, such as recycled materials from existing structures, which can be integrated into the system through appropriate redefinitions of the topological and geometric connection relationships.

Conclusions

The natural world, admired for its efficiency in solving problems, offers complex models that can be translated into algorithms describing form, as natural and computer systems share similar structural patterns, albeit often invisible. In design disciplines, these algorithms can generate not only representation models, but also concrete artefacts. This shows how the conversion of form into computer language does not reduce reality, but rather reveals its complexity. The cases presented here are examples of this, most notably the reinterpretation of the brick as a modular unit within a geometric language, where rules are extrapolated from natural morphologies.
The possibilities are not limited to visual representation: fractal parameterisation in *Grasshopper* allows for light and shadow simulations, ventilation assessments and thermo-visual optimisations, transforming the brick into a multifunctional architectural device. In this way, the design process approaches a synthesis between generative geometry and construction tradition capable of integrating formal complexity and material concreteness.

Acknowledgements

Although this research is a collective work, paragraphs *Introduction* and *Fractal Geometry: References and Digital Models* can be attributed to Michela Rossi and Giorgio Buratti, and *Designing complex factal structures: from broccoli to rosettes* to Giorgio Buratti and Andrea Rossi. The algorithmic definitions in figures 2-5; 7 are by Buratti Giorgio, while the algorithm that calculates the geometries in figure 6 is by Andrea Rossi.

Notes

[1] In mathematics, the Lebesgue measure is the measure typically used for subsets of a Euclidean space of any dimension. It is a complete positive measure that generalises the elementary concepts of area and volume of subsets of Euclidean space.

[2] The definition is attributed to Charles Hermite, an eminent French mathematician who, in a letter to a colleague, defined continuous but non-differentiable functions as 'monstrous' or 'pathological' because they challenged the intuitive notions of regularity and differentiability on which much of the mathematical analysis of the time was based.

[3] Goethe quotes and uses it in some of his writings, especially in *Maxims and Reflections* (*Maximen und Reflexionen*, posthumous collection of 1833), where similar formulations on the natural limits of growth and perfection can be found.

[4] A species of water lily characterised by large leaves, supported by a complex system of radial ribs and cross veins, which ensure lightness and structural strength.

[5] Munari simplifies Leonardo's observations on the design/shape of trees: Branches tend to curve upwards unless their weight or that of fruit prevents them from doing so. The reason for this is that each branch competes for greater exposure to sunlight; Branches growing in the lower part of the tree are larger than those growing in the upper part; Branches that are more central, and therefore less exposed to light, tend to wear out more and appear less attractive; The most attractive and vigorous branches are those at the top of the tree due to their exposure to light and air; When the branches of a tree fork, the angle they form is always the same, regardless of which branch is considered; Statement 5 is always true unless the branch is old. The older it gets, the more obtuse the angle becomes; When a branch divides into two branches, the inclination of the two branches will be different, and the thinner one will be more inclined; When a branch divides into two branches, the sum of the sections of the latter is equal to the section of the parent branch; The inclinations of the main branches are as many as the new branches that start from them without colliding; This inclination bends more the thicker the branches are; The point of intersection of the leaf always leaves a scar on the branch to which it was attached until, due to the age of the tree, the bark cracks and bursts.

[6] In fact, Roman broccoli is a medium-early autumn-winter variety of cauliflower.

[7] *Wasp* is a plug-in for *Grasshopper*, developed in *Python*, which offers combinatorial tools for designing with discrete elements. The description of each part includes all the necessary information for the aggregation process (part geometry, position, and orientation of connections), while providing a set of valuable tools for constraining the resulting aggregation. *Wasp* was developed by Andrea Rossi as part of research into digital materials and discrete design at the DDU Digital Design Unit at TU Darmstadt, led by Prof. Oliver Tessmann.

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From Graphic Analysis of Equilibrium to Architectural Design. Cèsar Martinell

Cinta Lluis-Teruel, Josep Lluis i Ginovart

Abstract

Graphic statics is a structural calculation method derived from the concept of the thrust line and used by Catalan Modernism. A disciple of Antoni Gaudí, Cèsar Martinell, employed it in the design of 15 wineries between 1918 and 1922, which are now known as cathedrals of wine. One of them, the Pinell de Brai winery, illustrates the transformation of an initially projected structure with wooden trusses into one using masonry arches, which is the object of this study. By analyzing eight of the sketches using a graphic restitution methodology, it is possible to compare the masonry arches to the shapes of the catenary and the parabola, with an accuracy of ± 0.077 m for scale 1:100, and ± 0.052 m for scale 1:50. This analysis has made it possible to determine how the design process was developed: from trusses, to structural definition through trial and error using architectural drawing with graphic statics, and finally, the executed project featuring tied arches. In conclusion, none of the 14 drawn arches is strictly parabola or a catenary. The eight arches of the central nave tend toward the catenary shape, while the smaller-span arches of the side naves tend toward the parabola. The four masonry arches in the final project were drawn through point transposition using an auxiliary construction with a hanging chain, where the architectural structure was resolved using graphic methodologies.

Keywords: arches, catenary, graphic statics, Cèsar Martinell, parabola

Graphic statics and architectural design

Architectural structures were, for many years, the result of an experimental methodology until Robert Hooke (1635-1703) published *A description of helioscopes, and some other instruments*, in which he identified the ideal shape of an arch as the catenary curve [Hooke 1676, p. 31]. The scientific development of this curve was later addressed by Johann Bernoulli (1667-1748) in *Solutio problematis funicularii* [Bernoulli 1691] and Christiaan Huygens (1629-1695), in *Solutio eiusdem problematis* [Huygens 1691].

The mechanics of masonry structures conceptualized the thrust line as the locus of points through which internal forces pass within a system of given cutting planes [Huerta 2024], based on the mathematical foundations laid by Reverend Henry Moseley (1801-1872) [Moseley 1835].

This circumstance led to significant advances in graphic statics, which proved decisive for the architectural design of Catalan Modernism, particularly in the works of Rafael Guastavino Moreno (1842-1908) [Goodyear 1906] and Antoni Gaudí i Cornet (1852-1926) [Huerta 2006]. Both were trained in the concept of graphic transposition of structure into architectural design by Joan Torras Guardiola (1827-910) [Graus, Martin-Nieva 2015].

In addition to the Barcelona School of Architecture, established in 1875, the theory of ceramic vault construction also spread through the Architects' Association of Catalonia.

Fig. 1. Detail of the main beam of the Pinell de Brai Cooperative, built with brick arches. Image credit: Department of Culture of the Generalitat de Catalunya.

José Domènech i Estapà (1858-1917) suggested that parabolic shapes result from the equilibrium lines of a system with uniformly distributed loads, while catenary curves stem from the structure's self-weight [Domènech 1900]. Jaime Bayó Font (1873-1961) approached ceramic structures as flexible shells with different elastic coefficients in tension and compression [Bayó 1910]. Jeroni Martorell i Terrats (1876-1951) analyzed the use of iron tie-rods in masonry arches [Martorell 1910].

In structural science, the equilibrium conditions of a structure under a given load system can be analyzed using graphical statics, which employs the graphical representation of forces as vectors. Through this and with its adjustment, the architectural project can be produced, which is the subject of this paper. It is, therefore, a reflection on the relationship between structure and form, examined through the contribution of the graphic process and the skill involved in adjusting complex geometric forms using architectural drawing.

The study takes as a reference the figure of Cèsar Martinell i Brunet (1888-1973), a disciple and collaborator of Gaudí, who built 15 wineries between 1918 and 1922, known as cathedrals of wine, using graphic statics for the construction of their masonry arches. In the Historical Archive of the College of Architects of Catalonia in Barcelona ($COACAH_B$), the preliminary sketches (drawing C222-170) and the project (drawing H108I/18/170) for the Winery and Oil Mill of the Agricultural Cooperative of Pinell de Brai are preserved.

The building was constructed between 1918 and 1922 and has adjoining naves, one of which has two floors and is used as an oil mill, while the others are used as a wine cellar, where there is a structure formed by brick arches (fig. 1).

The analysis of the completed structure determined that none of the 28 arches defined by the function *f(a)* geometrically satisfy the equation of the catenary *f(c)*, nor that of the parabola *f(p)*. The fourteen smaller arches tend toward the parabolic function *f(p)*, while the larger-span arches tend toward the catenary function *f(c)* [Lluis i Ginovart et. al. 2017] (fig. 2).

Object of study and methodology

With knowledge of the completed work, the aim of this research is to analyze the evolution of the design process of the Pinell de Brai project through graphic documentation that served as the basis for the execution of the structure. The study focuses on the use of sketches to determine the masonry arches and to explore the relationship between structure and form through the following architectural drawings:

- H101I/6/reg. 2502: transverse section (0.606 × 0.390 m), graphite pencil on paper, scale 1:100;
- H103A/14/reg. 2290: transverse section (0.693 × 0.414 m), heliographic copy, scale 1:100;
- H103A/1/reg. 2293: detail of longitudinal and transverse sections (1.101 × 0.396 m), heliographic copy, scale 1:50;
- C222/170/1.1: detail of two central nave arches with graphic calculation (0.448 × 0.463 m), graphite pencil on paper, scale 1:50;
- C222/170/1.2: detail of two half-arch sections of the central nave with graphic calculation (1.025 × 0.491 m), graphite pencil on paper, scale 1:50;
- C222/170/1.5: transverse section (0.807 × 0.501 m), heliographic copy, scale 1:100;
- C222/170/2.4: detail of longitudinal and transverse section (1.378 × 0.498 m), graphite pencil on paper, scale 1:50;
- C222/170/2.6: detail of a central nave arch with graphic calculation (0.691 × 0.479 m), graphite pencil on paper, scale 1:50.

The methodological error in the trace restitution (*Ett*) depends on the drawing scale. It is determined as the sum of the precision of the original trace (*Ept*) (drawing

	Section A1				Section A2				Section A3				Section A4			
	A1.T1.a	A1.T2.b	A1.T3.c	A1.T4.d	A2.T1.a	A2.T2.b	A2.T3.c	A2.T4.b	A3.T1.a	A3.T2.b	A3.T3.c	A3.T4.d	A4.T1.a	A4.T2.b	A4.T3.c	A4.T4.d
Crown height	2,76	12,48	2,66	9,23	2,72	12,52	2,71	9,25	2,73	12,49	2,70	9,35	2,74	12,32	2,70	9,17
Span of the arch	2,91	13,55	2,87	10,10	2,89	13,57	2,82	10,07	2,89	13,59	2,84	10,08	2,91	13,53	2,84	9,99
f/l	0,95	0,92	0,93	0,91	0,94	0,92	0,96	0,92	0,95	0,92	0,95	0,93	0,94	0,91	0,95	0,92

	Section A5				Section A6				Section A7			
	A5.T1.a	A5.T2.b	A5.T3.c	A5.T4.d	A6.T1.a	A6.T2.b	A6.T3.c	A6.T4.d	A7.T1.a	A7.T2.b	A7.T3.c	A7.T4.d
Crown height	2,67	12,49	2,66	9,38	2,69	12,53	2,65	9,30	2,67	12,37	2,68	9,39
Span of the arch	2,88	13,58	2,81	10,09	2,87	13,59	2,81	10,07	2,89	13,54	2,82	10,09
f/l	0,93	0,92	0,95	0,93	0,94	0,92	0,94	0,92	0,92	0,91	0,95	0,93

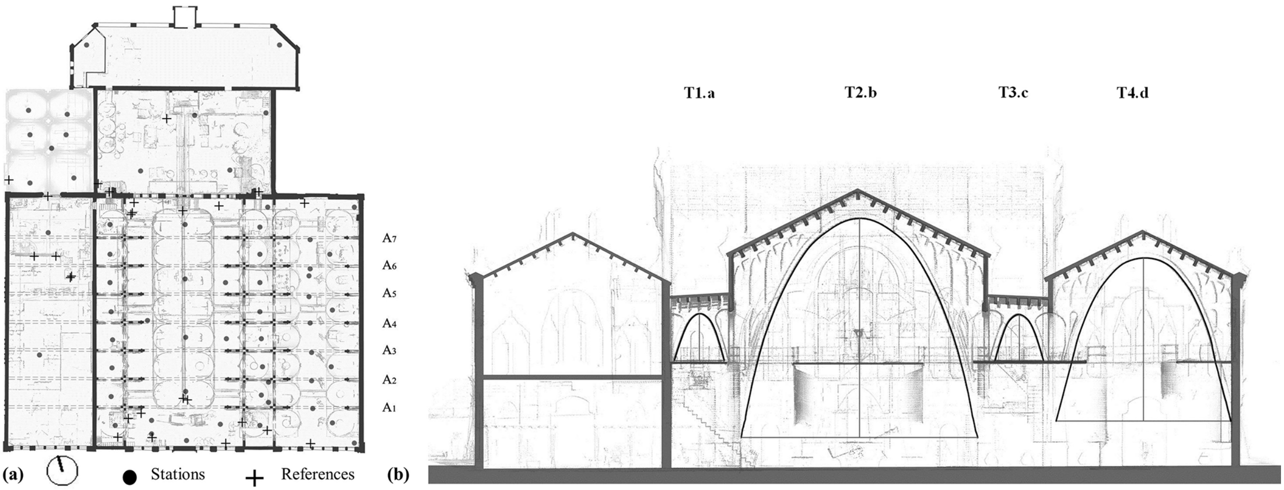


Fig. 2. Elevation (TLS) Sindicato Agrícola de Pinell de Bray. Leica Scan Station P40 (2015). Units of length expressed in meters.

H1011/6/reg. 2502), in which 13-dimension lines were noted and used as the basis for calibration, resulting in a root mean square error of 0.001, with a tolerance of ± 0.026 m defined as *TTi.i*. The pixel reference of a graphite line at scale *Elt*, (1:100 = ± 0.041 m) and (1:50 = ± 0.021 m), and the estimated digital restitution error is considered as *Eit* (1:100 = ± 0.010 m) and (1:50 = ± 0.005 m):

$$Ett = \Sigma\ (Ept, Elt, Eit) \qquad (1)$$

The resulting errors are Ett_{100} = ± 0.077 m and Ett_{150} = ± 0.052 m, taking the measurement of the smallest arch as a reference (*TTa.1* and *TTc.3*) *l* = 2.650 m.

$$Ett_{100} = \pm\ 2.906\%;\ Ett_{150} = \pm\ 1.962\%$$

The nomenclature for the executed arches is: (*T1.a*, *T1.b*, *T1.c*, *T1.d*); for the project arches: (*Ta.1*, *Tb.2*, *Tc.3*, *Td.4*). The graphic construction of the arches is based on the theoretical dimensions established through the drawn measurements of the trace (drawing H1011/6/reg. 2502), which are taken as the theoretical references (*TTa.1*, *TTb.2*, *TTc.3*, *TTd.4*). The differences between them are not significant in terms of the rise *(f)* and the span (*l*).

Methodology for the graphic comparison of the curve traces

The graphic verification is carried out using the functions of the parabola and the catenary, where *p* represents the weight per unit length of a hanging element, and T_o minimum horizontal tension:

$$f(p) = p\,\frac{x^2}{2T_0} \tag{2}$$

$$f(c) = T_0/p.\cosh\left(\frac{x.p}{T_0}\right) \tag{3}$$

The process is carried out within a Cartesian coordinate system (x, y), where the coordinates ($x = l$) and ($y = f$) represent the span and the rise, respectively. Ten points are defined per branch for both figures, distributed along the x-axis, allowing the establishment of *(lcx)* and *(lpx)*, similar to those used in funicular polygons. The parabola is drawn by knowing the vertex, the axis, and the springing points, using projective bundles over a parallelogram (f, $l/2$) divided into 10 segments. The catenary is determined using 10 points, whose projection follows a similar projective sequence (*yci/n*). Considering that, when the coordinates (*yci* = *ypi*) of the catenary *f(c)* and the parabola *f(p)* are equal, the coordinates *xci* are always greater than *xpi*. In this way, it is possible to verify the projective difference (*xci* - *xpi*) between the catenary *f(c)* and the parabola *f(p)* (fig. 3).

The difference depends on the drawing scale and on the ratio between the rise and the span of the arch. Verification is carried out by constructing a canonical reference (10 m), which corresponds to the average span of the arches in the project. In this way, it is observed that the smaller the rise-to-span ratio, the more similar the two curves become. The greatest distortions between the widths of the two figures occur in interval [7], which corresponds to the projection between 30% and 40% from the springing points (l_1, l_2).
Thus, for rise/span ratios (*f/l*: 0.25, 0.50, 0.75, 1.00), the corresponding differences (*xci* - *xpi*) are: 0.069 m, 0.194 m, 0.313 m, 0.414 m.
In delineation, these canonical curves yield values of: [*E*: 1/100 (*xci* - *xpi*) = 0.000 m, 0.002 m, 0.003 m, 0.004 m], while [*E*: 1/50 (*xci* - *xpi*) = 0.001 m, 0.004 m, 0.006 m, 0.008 m]. Similar results are found in the theoretical arches (drawing H1011/6/reg. 2502) (*TTa.1*, *TTb.2*, *TTc.3*, *TTd.4*), with differences in the built work of 0.115 m, 0.469 m, 0.396 m, and 0.414 m respectively.

(a) Difference between canonical functions f(c)-f(p)

Stretch	Interval	Rise/Span 0,25	0,5	0,75	1,00
V	1	0,000	0,000	0,000	0,000
1/10x(l/2)	2	0,027	0,067	0,102	0,127
2/10x(l/2)	3	0,040	0,106	1,666	0,213
3/10x(l/2)	4	0,047	0,145	0,227	0,299
4/10x(l/2)	5	0,061	0,175	0,278	0,370
5/10x(l/2)	6	0,069	0,194	0,313	0,414
6/10x(l/2)	7	0,070	0,198	0,375	0,426
7/10x(l/2)	8	0,065	0,185	0,301	0,400
8/10x(l/2)	9	0,052	0,150	0,243	0,326
9/10x(l/2)	10	0,031	0,009	0,17	0,196
l/2	11	0,000	0,000	0,000	0,000

(b) Difference between theoretical arches f(c)-f(p)

Stretch	Interval	Rise/Span TTa.1	TTb.2	TTc.3	TTd.4
V	1	0,000	0,000	0,000	0,000
1/10x(l/2)	2	0,034	0,151	0,127	0,127
2/10x(l/2)	3	0,058	0,245	0,205	0,213
3/10x(l/2)	4	0,083	0,342	0,285	0,299
4/10x(l/2)	5	0,099	0,419	0,354	0,370
5/10x(l/2)	6	0,115	0,469	0,396	0,414
6/10x(l/2)	7	0,119	0,482	0,407	0,426
7/10x(l/2)	8	0,111	0,451	0,382	0,400
8/10x(l/2)	9	0,091	0,365	0,311	0,326
9/10x(l/2)	10	0,053	0,202	0,187	0,196
l/2	11	0,000	0,000	0,000	0,000

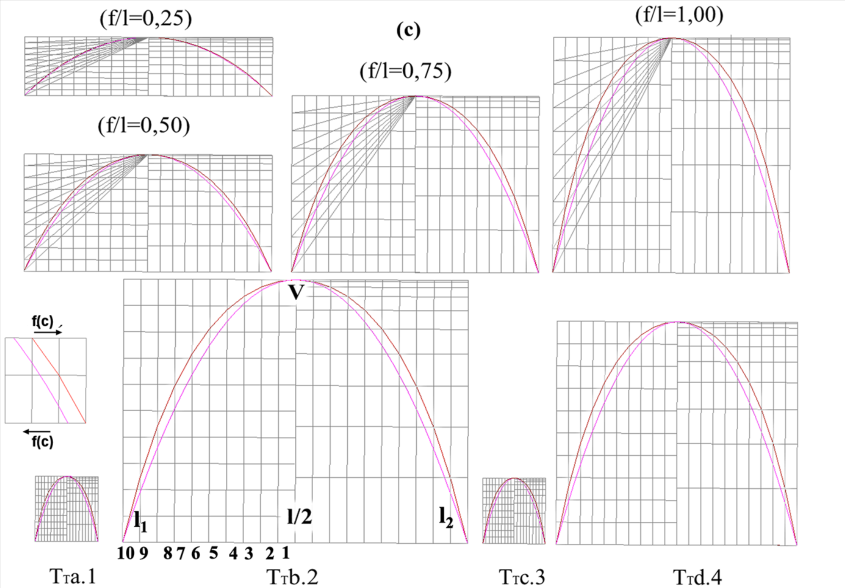


Fig. 3. Relationship between the shapes of the masonry arches and the functions of the catenary f(c) and the parabola f(p). Units of length expressed in meters, referring to a standard of 10 m arc length.

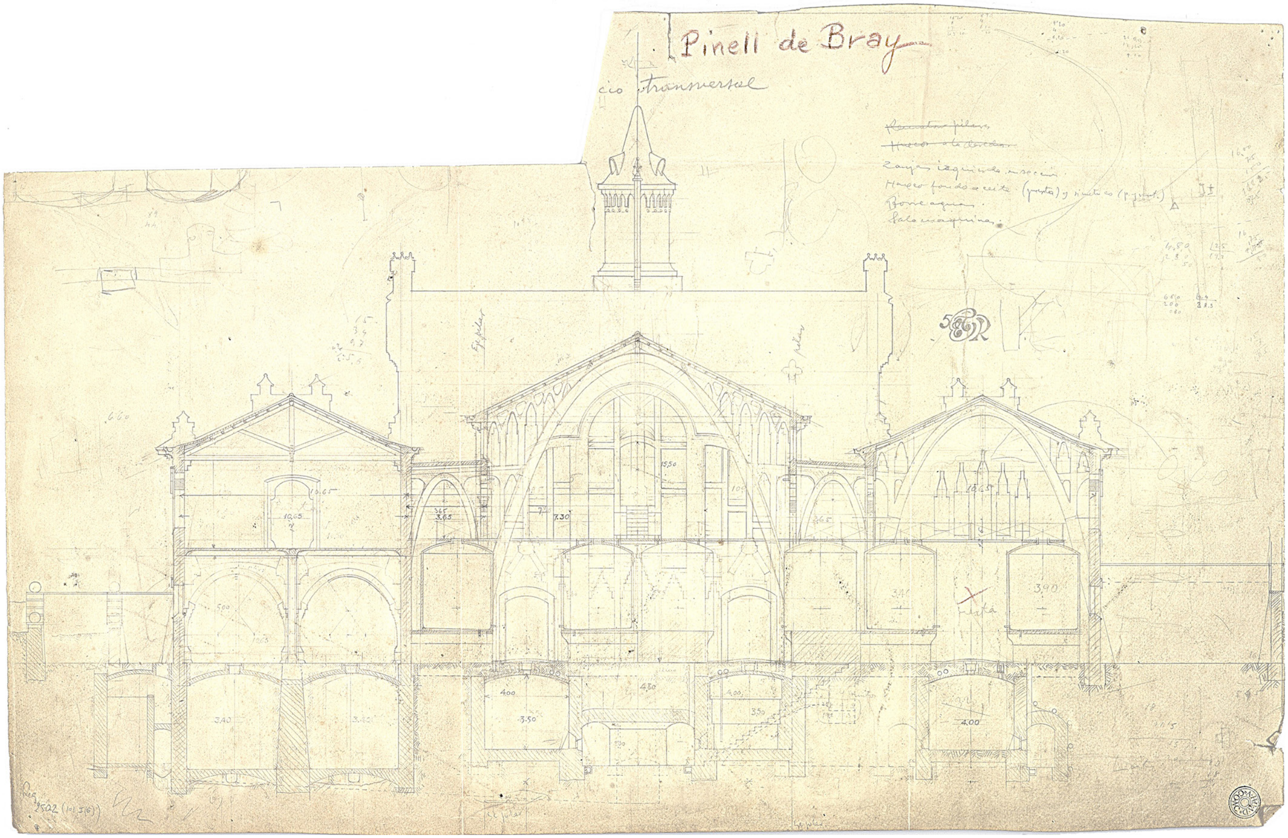


Fig. 4. Trace of drawing H1011/6/reg. 2502 as the basis for project (P1) (drawing C222/170/1.5) and (P2) (drawing H103A/14/reg. 2290). Image credits: COAC AH$_B$ Archive.

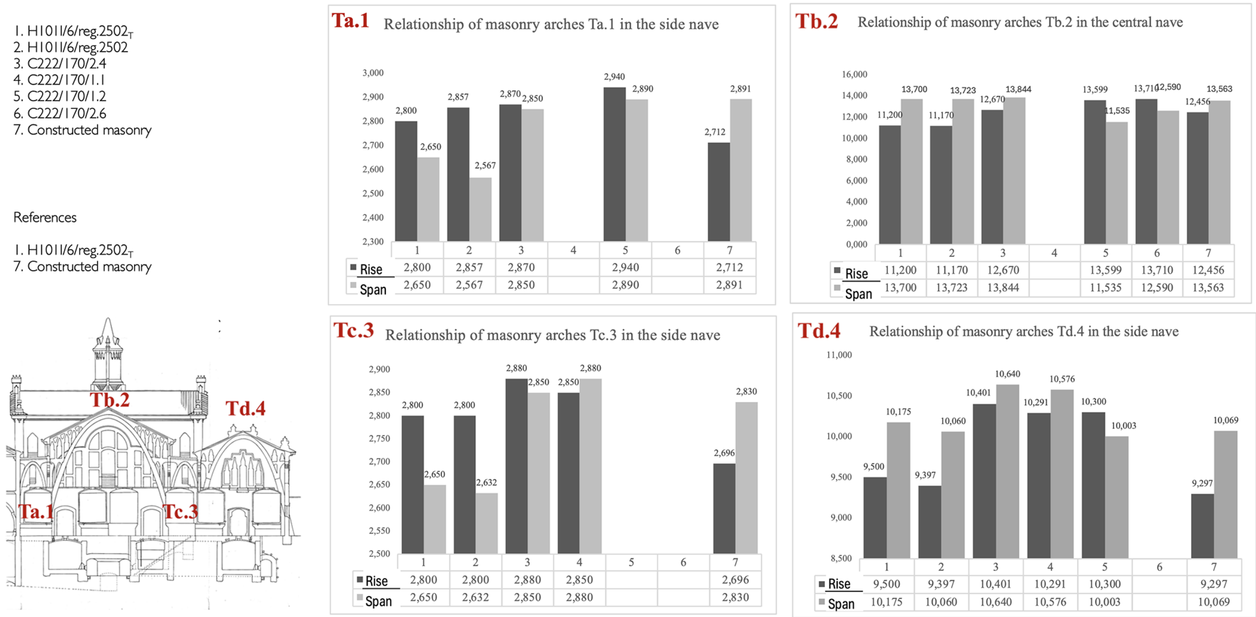


Fig. 5. Design trials of the masonry arch dimensions with reference to the theoretical levels of the initial project (1. H1011/6/reg. 2502T) and to the executed work (7. constructed masonry). Units of length expressed in meters.

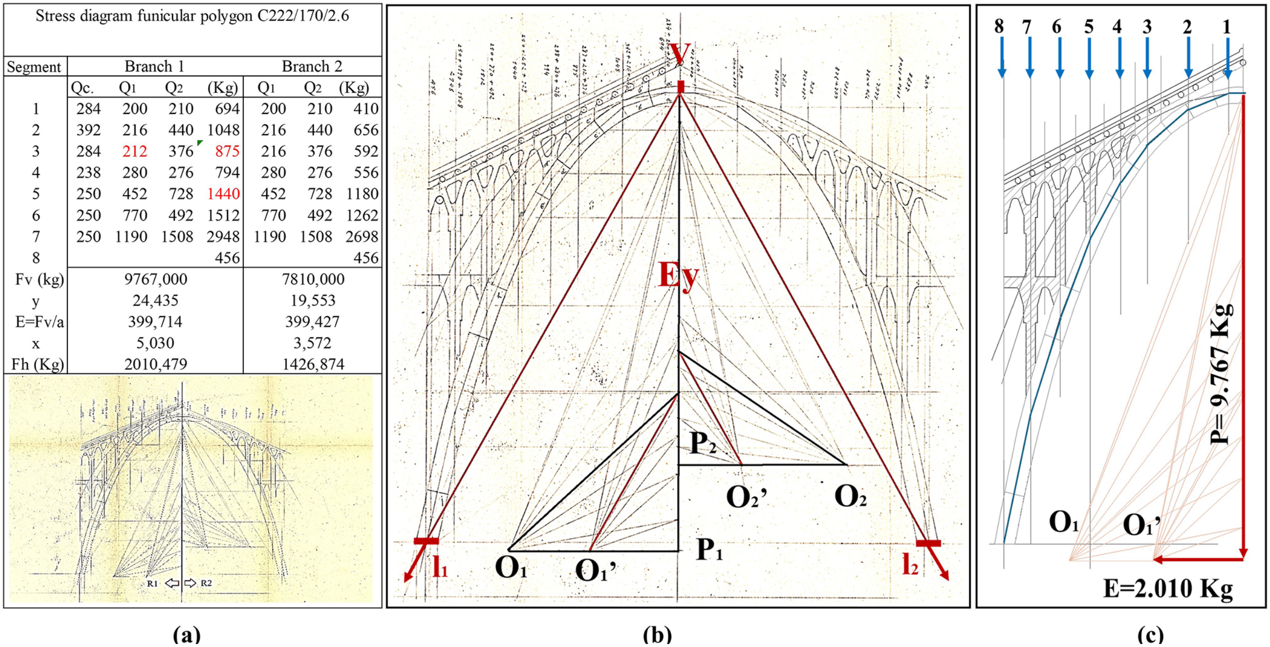
Initial modification of the project: drawing C222/170/1.5

In the transverse section (drawing C222/170/1.5), all three naves are covered with wooden trusses, and this is considered the original design *P1*. A correction made in strong graphite is visible in the basement area, adapting it to the topography. Additionally, very fine graphite lines appear beneath two of the trusses, indicating their replacement by masonry arches. In project (drawing H103A/14/reg. 2290), the nave designated for the oil mill retains its original truss structure, while the two intended for the winery are constructed with four masonry arches. Moreover, the ground floor section shows clear adaptation to the existing topography and is regarded as the foundation of the new design *P2*. Both traces share a common base, i.e. the matrix (H1011/6/reg. 2502) (fig. 4) where the superposition of both proposals can be observed the trusses from the initial project (C222/170/1.5) and the masonry arches from drawing H103A/14/reg. 2290. This sketch preserves the section of the basement level from design *(P1)*, which would later be modified in the final project *(P2)*.

The shortage of wood and steel resulting from the First World War, along with the financial constraints of the co-operatives, led to the replacement of the roof trusses with brick masonry arches [Llorens 2013]. According to the construction budget, the common brick was to be sourced from Benissanet and Tortosa; the facing brick from Mora; and the molded brick from Reus all of which are nearby towns (drawing C 222/170).

Later modifications and the use of graphic statics for design trials

The design change led to a dimensioning process using funicular polygons for the four arches. When referencing the dimensions of those with annotated measurements



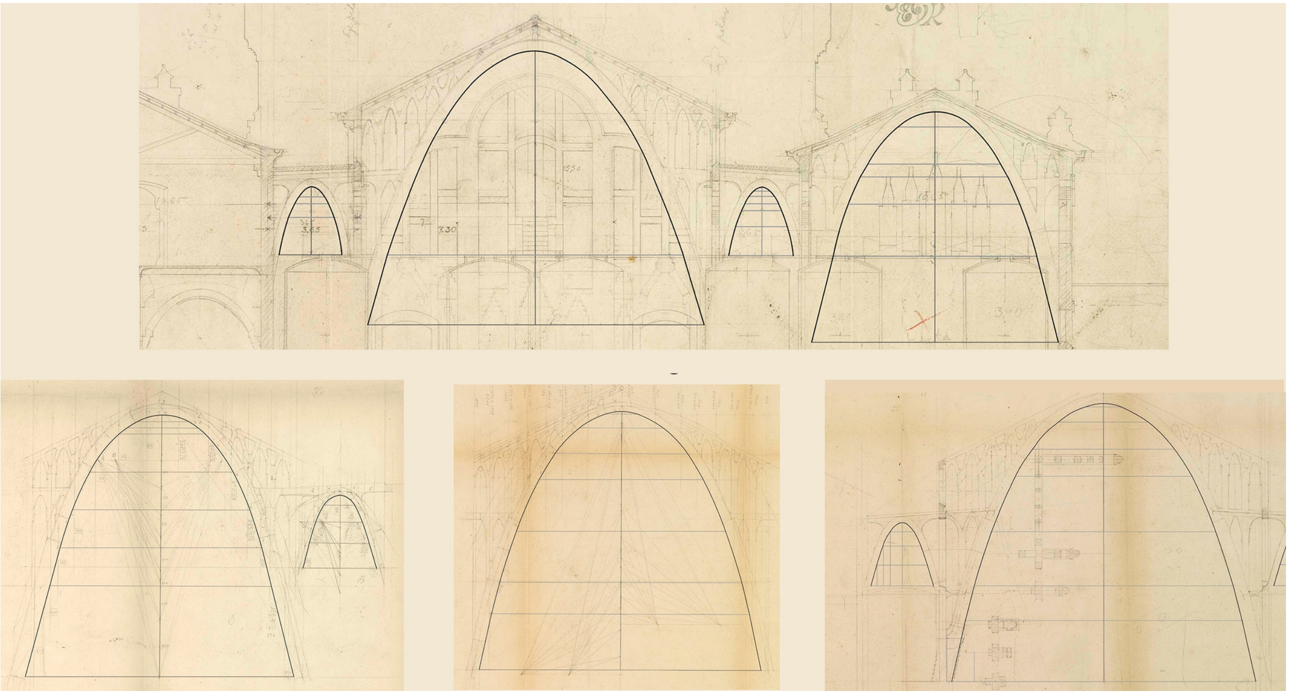
Stress diagram funicular polygon C222/170/2.6

Segment	Branch 1				Branch 2		
	Qc.	Q1	Q2	(Kg)	Q1	Q2	(Kg)
1	284	200	210	694	200	210	410
2	392	216	440	1048	216	440	656
3	284	212	376	875	216	376	592
4	238	280	276	794	280	276	556
5	250	452	728	1440	452	728	1180
6	250	770	492	1512	770	492	1262
7	250	1190	1508	2948	1190	1508	2698
8				456			456
Fv (kg)	9767,000				7810,000		
y	24,435				19,553		
E=Fv/a	399,714				399,427		
x	5,030				3,572		
Fh (Kg)	2010,479				1426,874		

Fig. 6. Funicular polygons of masonry arches Tb.2 (drawing C222/170/2.6). Units of length expressed in meters. Image credits: COAC AH_B Archive.

(drawing H1011/6/reg. 2502T), differences in all dimensions can be observed. In this way, the design trial (drawing C222/170/1.1) increases both the rise *(f)* and span *(l)* of arches *Tc.3* and *Td.4*. In drawings C222/170/1.2 and C222/170/2.6, both the rise and span are increased for arch *Ta.1*, and the rise is also increased for *Tb.2* (fig. 5).
Develop some preliminary layouts before the final solution, forming two funicular polygons for *Tb.2* and *Tc.3* in drawing C222/170/1.1, two more for arches *Tb.2* and *Td.4* in drawing C222/170/1.2, and another one for *Tb.2* in drawing C222/170/2.6.
Each masonry arch operates with two branches (R_1, R_2). In R_1, the self-weight and the load of the upper finish (Q_1, Q_2) are applied, along with the live load of the roof (*Qc*,) while R_2 includes only Q_1 and Q_2 (fig. 6a). The funicular is constructed using eight segments of the arch, with the line passing through the center of the core of the elastic section. The resultant used to determine the thrust *E* is constructed with a triangle located at the center of the section, with vertex *V*, and at the springing point of the arch l_1 and l_2, aligned along a central axis *Ey*. A provisional pole is drawn for each branch, O_1 and O_2, followed by the final poles O_1' and O_2' (fig. 6b). The resulting vertical component *P* is the sum (P_1 - *8*), and the horizontal component is (*P* - *O'*) (fig. 6c).
The tests show that the arches in the naves are segmental ($f/l > 1$), whereas in the initial project they were lowered ($f/l < 1$), and therefore, the trials would result in a thrust *E* smaller than that of drawing H1011/6/reg. 2502_T.
The analysis of the curves traced for the masonry arches is carried out by dividing the curve into two branches along the vertical axis that passes through the vertex (*V*), where the half-span (*l/2*) is divided into ten segments (xa_{1-10}) determining (ya_{1-10}). This point serves as a reference to determine the measurement differences with respect to the parabola and the catenary:

$$(ya_{1-10}) = (yp_{1-10}) = (yc_{1-10}) \quad (4)$$



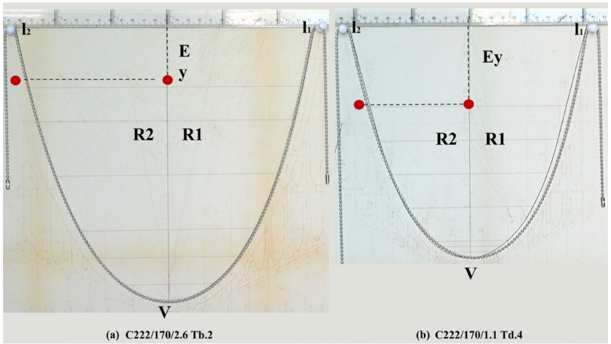


Fig. 7. Detail of the alignment lines in the trace of the masonry arches. Image credits: COAC AH_B Archive.

Fig. 8. Verification of the geometric traces of the arches using an inverted chain.

In this way, the following is established:

$$dp = (xa_{1-10} - xp_{1-10});\ dc = (xa_{1-10} - xc_{1-10}) \qquad (5)$$

It is observed that the layout of the two branches R_1 and R_2 is not exactly symmetrical, and that none of the fourteen curves correspond exactly to *f(xc)* catenaries or *f(p)* parabolas. Of the 144 points analyzed from the eight arches of the central naves (*Tb.2*, *Td.4*), 12.50% of the points (*f(p)*) approximate the parabola, while 87.50% (*f(c)*) tend toward the catenary. Of the 100 points from the arches of the side naves (*Ta.1*, *Tc.3*), 75.00% (*f(p)*) approximate the parabola, while 25.00% (*f(c)*) tend toward the catenary. In the tracing of the curves, certain points are marked in graphite along the curve's axis and are transferred perpendicularly toward branch R_2 of the curve, located to the right of the drafter. This suggests that the function *f(a)* was drawn using a point transposition method (fig. 7).

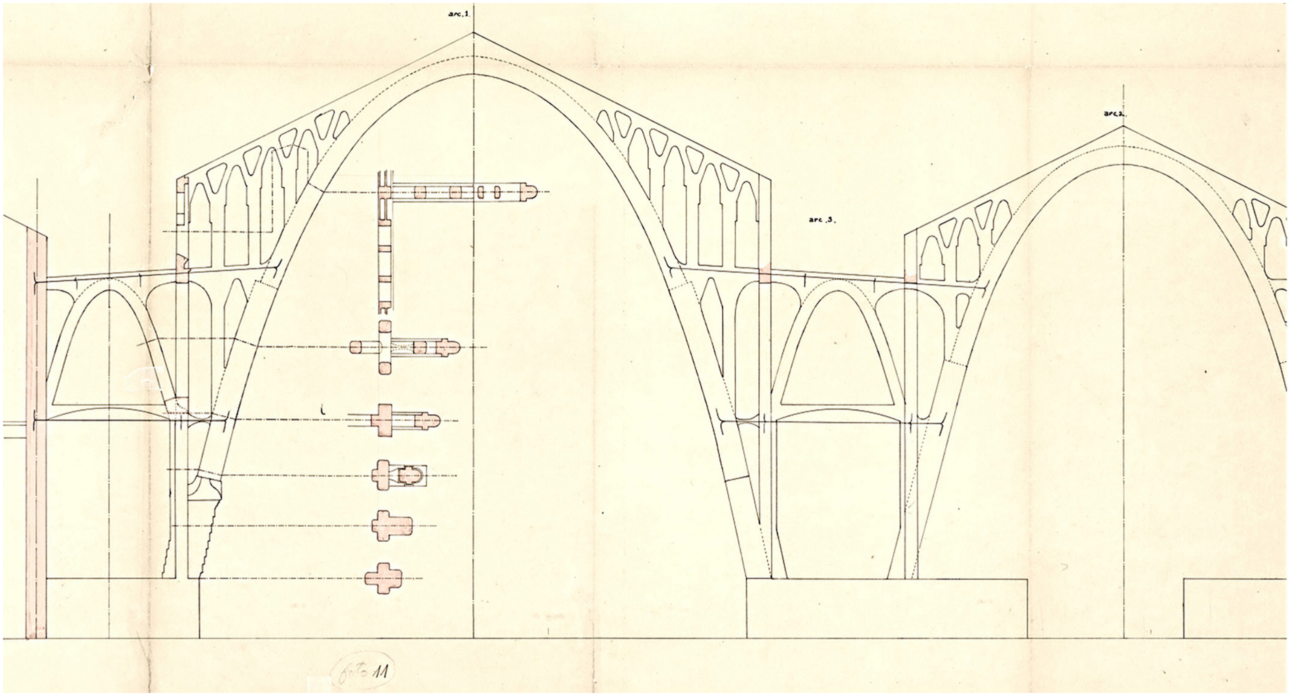
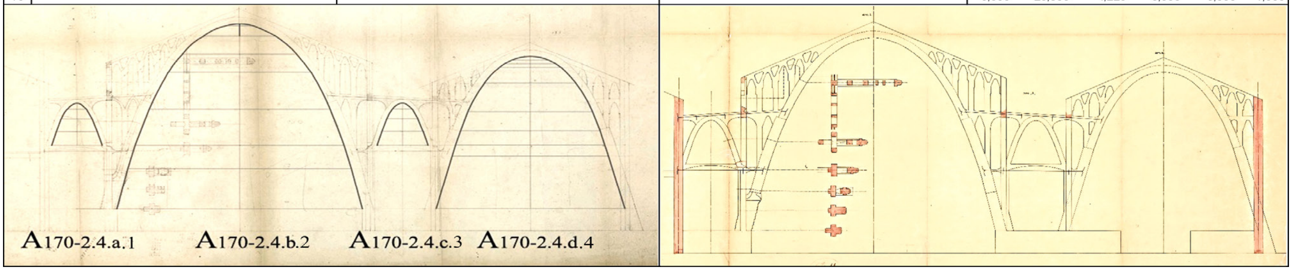


Fig. 9. Details of the anchors in the final section of the modified project (drawing H103A/11/reg. 2293). Image credits: COAC AH$_B$ Archive.

P	AC22/170/2.4.a.1						AC22/170/2.4.b.2					
P	(x0-xi)	y	Δ(x0-xi)	Δy	%Δx	%Δy	(x0-xi)	y	Δ(x0-xi)	Δy	%Δx	%Δy
1	5,700	0,000	0,000	1,880	1,000	0,000	27,700	0,000	0,000	5,770	1,000	0,000
2	4,580	1,880	1,120	1,730	0,804	0,328	25,200	5,770	2,500	2,960	0,910	0,228
3	3,410	3,610	1,170	1,310	0,598	0,629	23,580	8,730	1,620	4,930	0,851	0,345
4	2,180	4,920	1,230	0,820	0,382	0,857	20,410	13,660	3,170	5,050	0,737	0,539
5	0,000	5,740	2,180	0,000	0,000	1,000	16,090	18,710	4,320	2,460	0,581	0,739
6							12,880	21,170	3,210	2,460	0,465	0,836
7							8,140	23,630	4,740	1,390	0,294	0,933
8							3,160	25,020	4,980	0,310	0,114	0,988
9							0,000	25,330	3,160	0,000	0,000	1,000
10												

P	AC22/170/2.4.c.3						AC22/170/2.4.d.4					
P	(x0-xi)	y	Δ(x0-xi)	Δy	%Δx	%Δy	(x0-xi)	y	Δ(x0-xi)	Δy	%Δx	%Δy
1	5,700	0,000	0,000	1,920	1,000	0,000	21,280	0,000	0,000	7,210	1,000	0,000
2	4,630	1,920	1,070	1,690	0,812	0,334	17,630	7,210	3,650	1,520	0,828	0,347
3	3,470	3,610	1,160	1,310	0,609	0,628	16,860	8,730	0,770	1,910	0,792	0,420
4	2,240	4,920	1,230	0,830	0,393	0,856	15,750	10,640	1,110	2,600	0,740	0,512
5	0,000	5,750	2,240	0,000	0,000	1,000	14,120	13,240	1,630	3,920	0,664	0,637
6							10,360	17,160	3,760	2,120	0,487	0,825
7							6,980	19,280	3,380	0,510	0,328	0,927
8							5,800	19,790	1,180	0,490	0,273	0,951
9							4,220	20,280	1,580	0,520	0,198	0,975
10							0,000	20,800	4,220	0,000	0,000	1,000



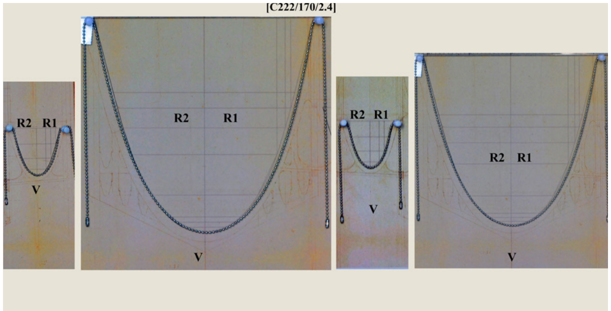


Fig. 10. Determination of the singular points in the tracing of the masonry arches.

Fig. 11. Verification of the geometric traces of the arches using an inverted chain.

A verification was carried out to determine the geometry of the traced curve by superimposing a chain with 320 beads per linear meter, weighing 8.059 grams, measured using a Mettler Toledo balance (PB303-S Delta Range). The setup was documented through photographs taken with a Nikon Digital Camera D5200, equipped with a Nikon DX SWN VR Aspherical (∞-0.28 m/0.92 ft Ø 52). It was observed that the transposition of measurements is performed along the vertical axis *Ey* and transferred onto branch R_2, located to the right of the trace. Furthermore, there is a high degree of alignment in the points of branch R_2 (fig. 8a, b), whereas the symmetry in branch R_1 of the curve is not always consistent (fig. 8b).

The definition of the project: drawing C222/170/2.4 and H103A/1/reg. 2293

With the alignments, the base for the final project is established, using the trace that defines the geometry of the arches in the transverse section, with six sections perpendicular to the cut, and with the details of the upper arcade (drawing C222/170/2.4). It also includes the first three bays of the longitudinal section, where auxiliary lines appear for drawing the masonry arches, as well as notes with numerical operations, though no funicular analysis is present. In

the heliographic copy H103A/1/reg. 2293, the arches are numbered, and the anchoring of the ties from the central nave arches to those of the side naves is highlighted, taking advantage of the floor slab (fig. 9).
The tracing of the arches is carried out through the transposition of measurements, and it is observed that there is no orderly sequence in the progression of the abscissas Δy. There is a convergence of auxiliary traces for arches *Ta.1*, *Tc.3*, and *Td.4* within the interval 0.629%-0.637% from the springing points l_1 *and* l_2, which is drawn with a straight line. This part of the curve is where *f'(a)* reaches its maximum slope. The point of minimum curvature in all the arches appears in the segment 0.825%-0.857%, and the vertex *V* is located where *f'(a)* = 0 (fig. 10). In the verification using a chain, a high degree of alignment is observed with branch R_2 of the traces of the four arches, which is where the transposition of measurements occurs (fig. 11).
On the other hand, when comparing the tracing parameters with those of the parabola and the catenary, it is observed that the dimensional results of *Ta.1* and *Tc.3* approximate the parabola, while *Tb.2* and *Td.4* tend toward the catenary. As for the lengths of the four arches, all of them fall within the methodological error range E_{tt150}= ± 1,962% of the catenary function (fig. 12).
In the geometry of the trace *Tb.2*, an increase of 1.470 m in the rise of the arch is noted compared to the original design H1011/6/reg. 2502T, while the span increases by only 0.144 m. As a result, its section is more elevated, and therefore its thrust *E* will be lower. The dimensions of this arch are close to those of the executed work (*f, l* = + 0.214, + 0.281 m) and the ratio is very similar (*f/l*, 0.915, 0.918).
The dimensions of the as-built arch *T4.d* are close to the *Td.4* of the initial project and differ from the modified drawing *C222/170/2.4*. The geometry of *Ta.1* and *Tc.3* is very similar to the original design, the modified design, and the actual construction.

Conclusion

It has been possible to determine how the design process was developed, with the structural definition carried out

	AC22/170/2.4.a.1					
	(x0-xi)	y	Δ(x0-xi)	Δy	%Δx	%Δy
Lf (xa) m			6,668			
L f(xp) m			6,653			
L f(xc) m			6,795			
L f(xp)- L f(xa) m	**0,015**				**0,225 %**	
L f(xc)- L f(xa) m	**-0,127**				**-1,905 %**	
Sf (xa) m²			5,424			
S f(xp) m²			5,451			
S f(xc) m²			5,909			
S f(xp)- S f(xa) m²	**-0,027**				**-0,498 %**	
S f(xc)- S f(xa) m²	**-0,485**				**-8,942 %**	

	AC22/170/2.4.b.2					
	(x0-xi)	y	Δ(x0-xi)	Δy	%Δx	%Δy
Lf (xa) m			30,507			
L f(xp) m			30,071			
L f(xc) m			30,667			
L f(xp)- L f(xa) m	**0,436**				**1,429 %**	
L f(xc)- L f(xa) m	**-0,160**				**-0,524 %**	
Sf (xa) m²			124,287			
S f(xp) m²			116,990			
S f(xc) m²			125,981			
S f(xp)- S f(xa) m²	**7,297**				**5,871 %**	
S f(xc)- S f(xa) m²	**-1,694**				**-1,363 %**	

	AC22/170/2.4.c.3					
	(x0-xi)	y	Δ(x0-xi)	Δy	%Δx	%Δy
Lf (xa) m			6,684			
L f(xp) m			6,674			
L f(xc) m			6,813			
L f(xp)- L f(xa) m	**0,010**				**0,150 %**	
L f(xc)- L f(xa) m	**-0,129**				**-1,930 %**	
Sf (xa) m²			5,443			
S f(xp) m²			5,473			
S f(xc) m²			5,931			
S f(xp)- S f(xa) m²	**-0,030**				**-0,551 %**	
S f(xc)- S f(xa) m²	**-0,488**				**-8,966 %**	

	AC22/170/2.4.d.4					
	(x0-xi)	y	Δ(x0-xi)	Δy	%Δx	%Δy
Lf (xa) m			24,708			
L f(xp) m			24,289			
L f(xc) m			24,783			
L f(xp)- L f(xa) m	**0,419**				**1,696 %**	
L f(xc)- L f(xa) m	**-0,075**				**-0,304 %**	
Sf (xa) m²			77,793			
S f(xp) m²			73,770			
S f(xc) m²			79,783			
S f(xp)- S f(xa) m²	**4,023**				**5,171 %**	
S f(xc)- S f(xa) m²	**2,000**				**2,571 %**	

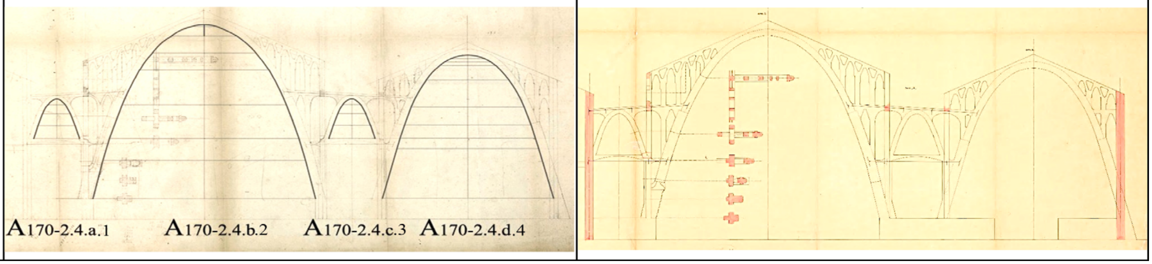


Fig. 12. Dimensional comparison of the arches with respect to the parabola and catenary.

through a graphic sequence: initial trusses, design trials of the arches using graphic statics, and the final project with tied arches. The executed work reflects the original geometry of arches *Ta.1*, *Tc.3*, and *Td.4*, as well as the increased rise of *Tb.2*. None of the 14 drawn arches corresponds strictly to a parabolic or catenary function. The eight arches in the central naves tend toward the catenary, while those with smaller spans in the side naves tend toward the parabola although all remain within the methodological margin of error for catenary restitution. The four masonry arches in the final project were drawn using point transposition, carried out through an auxiliary construction made with a hanging chain. Martinell relies on this simulation because it allows him to graphically plot a curve to draw the arches of the structure in a simpler way than plotting a parabola. The architectural structure was resolved using vector-based graphic methodologies, and its form was defined through the transposition of architectural drawing demonstrating the representational power of drawing in determining the structure of the architectural project.

Abbreviations and nomenclature

$COACAH_B$: Collegi Oficial Arquitectes Catalunya, Arxiu Històric Barcelona.
$COACAH_{To}$: Collegi Oficial Arquitectes Catalunya, Arxiu Històric Tortosa.
(f): rise of arches.
f(a): geometric function of masonry arches.
f(c): catenary function.
f(p): parabolic function.
(l): span of arches.
T1.a, *T1.b*, *T1.c*, *T1.d*: arches actually built on site.
Ta.1, *Tb.2*, *Tc.3*, *Td.4*: arches in the architectural project.

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The Geometry of the Invisible: Drawing as a Bridge between Chemistry and Design

Putri Anggita G., Huda M. Mahfuzh

Abstract

This paper investigates drawing as the critical epistemological bridge between the invisible laws of chemistry and the material realities of architecture. While chemists rely on graphic representation to render hidden molecular behaviors intelligible –from Bragg's static lattice sketches to Matsumoto's dynamic simulations– architects appropriate these same geometric codes to generate spatial form. We argue that drawing functions here as an "operative tool," translating crystalline logic into three distinct structural typologies: spanning, compression, and inhabitation. The study traces this translation through three specific case studies. First, the truncated icosahedron of fullerenes (C60) provides a universal diagram for spanning, realized in Takaaki Bando's bamboo artistic pavilions. Second, the self-interlocking, high-pressure lattices of Ice VI offer a speculative blueprint for compression, suggesting dense, vertical load-bearing systems for future infrastructure. Third, the "guest-host" chemistry of clathrate hydrates mirrors the metabolic logic of inhabitation, finding a powerful historical parallel in the permanent-transient structure of Kisho Kurokawa's Nakagin Capsule Tower. By mapping this trajectory, we demonstrate that drawing is not merely representational but generative: it is the medium through which the invisible performance of molecules is transformed into the habitable logic of the built environment.

Keywords: drawing, geometry, crystallography, generative design, molecular architecture.

Introduction: from the abstract to the tangible

Chemistry, unlike many other disciplines, engages with structures that are literally invisible to the human eye. Molecules, atomic bonds, and crystal lattices exist only through inference, measured behavior, and representation. Chemists rely on symbolic languages –such as molecular formulas, Lewis structures, or curved-arrow mechanisms– to translate the unseen molecular world into something communicable. As Kozma and Russell [Kozma 2000] argue, much of what constitutes chemistry exists at a molecular level inaccessible to direct perception, requiring inference through models, spectroscopic evidence, or computational visualization. This reliance on representation creates unique cognitive challenges for learners, who often reproduce drawings without connecting them to underlying processes. In this context, drawing is not simply a tool for visualization, but an epistemological necessity. It allows chemists and students to render intelligible the invisible order of matter, to reason about causal mechanisms, and to communicate complex ideas with precision and clarity [Bhattacharyya, Bodner 2005]. As Graulich [Graulich 2015] notes, the symbolic drawings used in organic chemistry are only the 'tip of the iceberg', encoding hidden layers of electron movement, energy change, and reactivity. Thus, drawings in chemistry function simultaneously as cognitive scaffolds, explanatory models, and communicative devices that

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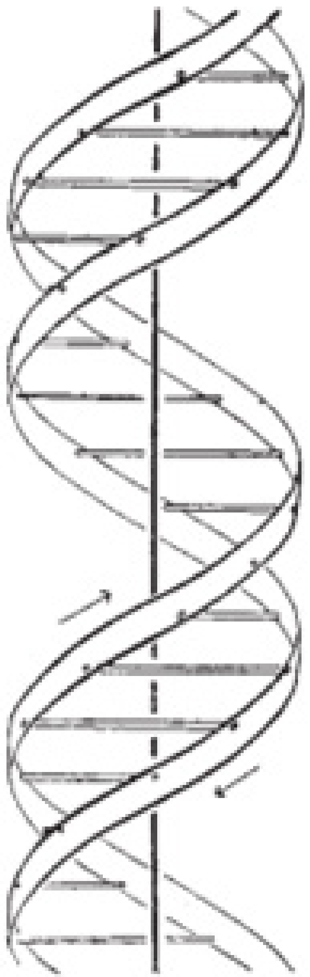
bridge the gap between visible symbols and invisible chemical reality. Through lines, angles, and spatial arrangements, drawing makes abstract scientific models explicit. This paper will demonstrate how drawing acts as a critical bridge between chemistry and design, connecting the invisible architecture of matter with its spatial and formal potential.

The historical and philosophical context of drawing and measurement

The exploration of geometry has long served as an impartial lens through which humanity observes and comprehends reality, transcending cultural or subjective bias. At the heart of this inquiry lies the philosophical distinction between intangible concepts and physical existence. Ancient thinkers such as Plato emphasized abstract, immutable forms, Aristotle sought to reconcile form and matter within a unified reality. Drawing presents a unique resolution to this enduring challenge by establishing a direct and privileged connection to physical objects –one that surpasses the descriptive capacities of words or numerical data.
A profound early influence on this way of knowing came from the Pythagoreans, who regarded mathematical principles not as detached abstractions but as inherent qualities of things themselves. For them, numbers mapped directly to geometric constructs: sequences defined lines, products defined planes, and triples defined volumes, imagined as arrangements of fundamental points. This conviction –that hidden mathematical harmony, expressed through simple ratios, reveals the intrinsic order of the universe– shaped later architectural, artistic, and scientific approaches to proportion and measure. Thus, measurement became not only a technical practice but also a knowledge defining act: the first step in understanding the invisible structures.
Beyond chemistry, the science of representation has historically grappled with the challenge of visualizing what cannot be directly perceived. Drawing operates as a materialized mediator for intellectualized ideals and abstract concepts, making them attainable and manageable [Cachão 2015]. In mathematics, diagrams serve as epistemic gateways to imaginary entities, in physics, schematic drawings convey hidden forces [Magnani 2013] and in the life sciences, drawing organizes knowledge of invisible subcellular processes [Tytler et al. 2020]. This epistemic role positions drawing at the intersection of observation, measurement, and imagination. It disciplines subjective creativity through conventions of rigor while enabling speculative reasoning. Historically, scientific illustration evolved from idealized, mythological images to modern demands for precision and objectivity, reflecting a shift from decorative representation to primary means of investigation grounded in geometric measurement [Cachão 2015].
This mathematical reasoning is vividly echoed in the way X-ray diffraction (XRD) patterns are read and transformed into images of crystalline lattices. The scattered rays, recorded as abstract peaks and lines, become intelligible only when interpreted as relations of symmetry, proportion, and repetition –concepts central not only to science but also to design. Bragg's Law itself, which links wavelength, distance, and angle through whole-number ratios, can be understood as an expression of harmony: invisible vibrations rendered as geometric order. What begins as a flat diagram of intensities on paper is ultimately redrawn into the three-dimensional architecture of matter, a process that closely parallels the work of architects who translate proportions and measurements into the spatial logic of buildings. In both cases, drawing mediates between the invisible and the visible, transforming hidden harmonies into structured forms. Reading diffraction patterns, then, is not merely a technical task but also an aesthetic act –an extension of the Pythagorean conviction that unseen harmonies give shape to the world.
This principle underpins modern chemistry and materials science, where invisible entities –such as bond lengths or crystal lattices– first appear as quantified measurements before being transformed into drawings that approximate reality. For instance, while the formula C_6H_6 provides numerical information about benzene, its stability is only understood through its resonance structure, rendered as alternating double bonds in a hexagon. This visual model, long inferred through drawing, was ultimately confirmed when atomic force microscopy produced images of benzene rings, presenting a literal depiction of the diagram's material existence.
Spectroscopy and crystallography extend this logic. X-ray diffraction measures the scattering of invisible rays through a crystal lattice, generating abstract numerical patterns that can be transformed into (fig. 1) the visual model of DNA's double helix [Watson, Crick 1953] or



This figure is purely diagrammatic. The two ribbons symbolize the two phosphate—sugar chains, and the horizontal rods the pairs of bases holding the chains together. The vertical line marks the fibre axis

Fig. 1. Molecular structure of nucleic acids (Watson, 1953).

the intricate folds of proteins. Nuclear magnetic resonance (NMR) translates the magnetic behavior of nuclei into spectra that chemists redraw as structural formulas, enabling reasoning about molecular connectivity. In each case, measurement captures the invisible, while drawing renders it explicit, bridging abstract quantification and material reality. Drawing, therefore, is not a mere supplement to scientific discourse but an epistemological necessity: the medium through which numbers and symbols are transmuted into knowledge of the world's hidden order.

Translating the invisible architecture of ice

The intricate geometry of ice's crystalline lattice is invisible to the naked eye. Its structure is revealed only through methods that translate the unseen into patterns of measure, most notably X-ray diffraction (XRD). When Sir William Henry Bragg (1862-1942) and his son Lawrence (1890-1971) pioneered the interpretation of diffraction in the early twentieth century, they gave scientists a way to 'see' into crystalline matter without direct vision. In 1921, W. H. Bragg hypothesized that ice possessed a hexagonal structure –akin to diamond, yet with a more open arrangement to account for its surprising lightness. Unlike denser crystals, the lattice of ice contains empty space, a property that explains why frozen water floats rather than sinks. Bragg calculated that each oxygen atom sat at the center of a tetrahedral arrangement (fig. 2), connected through hydrogen bonds to its neighbors. This representation, supported by Dennison's X-ray measurements, transformed ice from a familiar everyday substance into an object of geometric beauty and scientific wonder.

What is striking in Bragg's early work is that drawing functioned not merely as a final visualization step, but as a central engine of discovery. The process advanced from hypothesis to measurement –collecting abstract diffraction data of angles, intensities, and wavelengths– before culminating in the act of sketching. By translating these numerical values into lattice diagrams, Bragg enacted a kind of 'epistemic alchemy'; the drawing was not a decorative supplement, but the requisite medium that transformed scattered signals into a definitive, structural form.

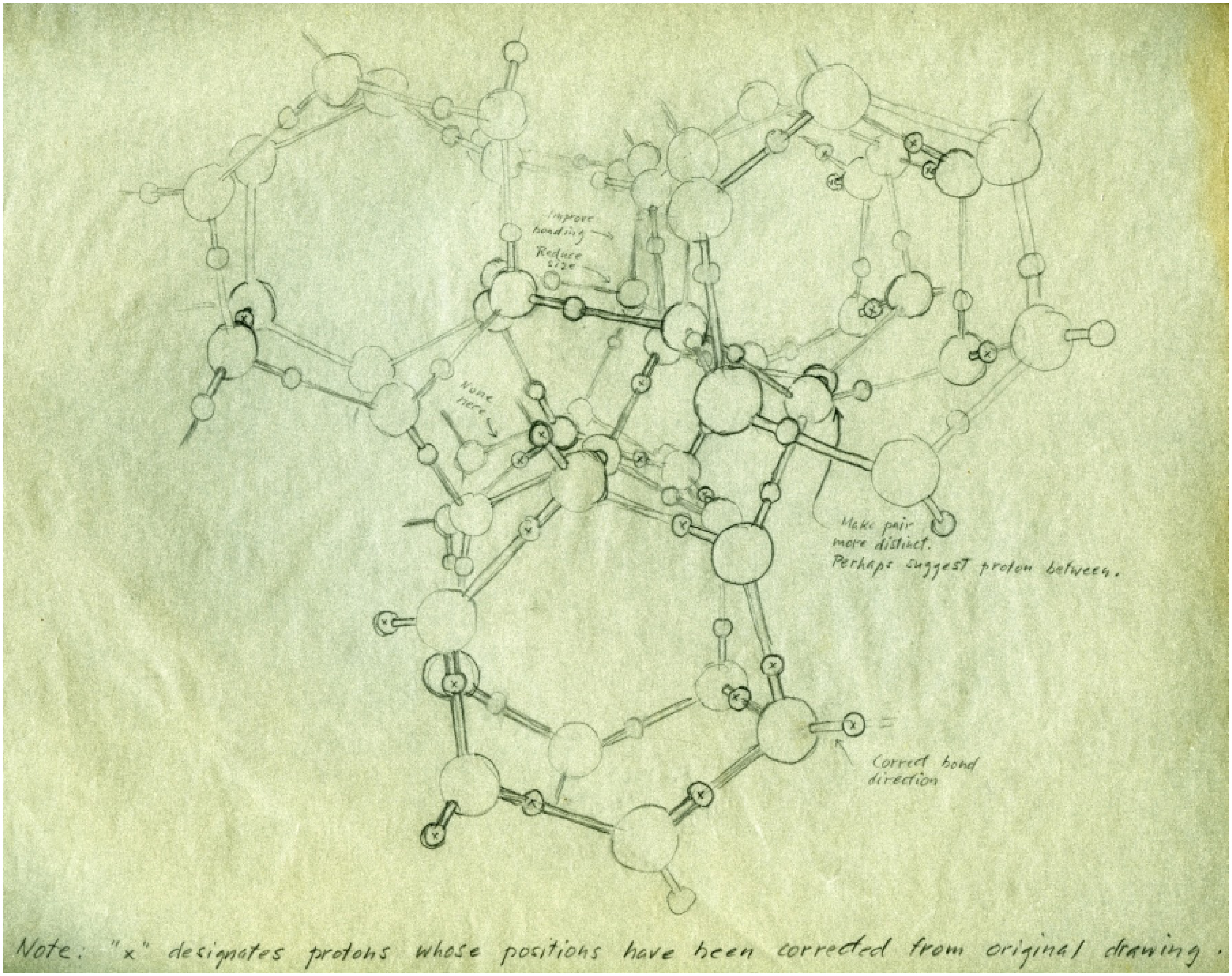


Fig. 2. Annotated pencil sketch of the structure of ice. 1964. (Hayward, 1964).

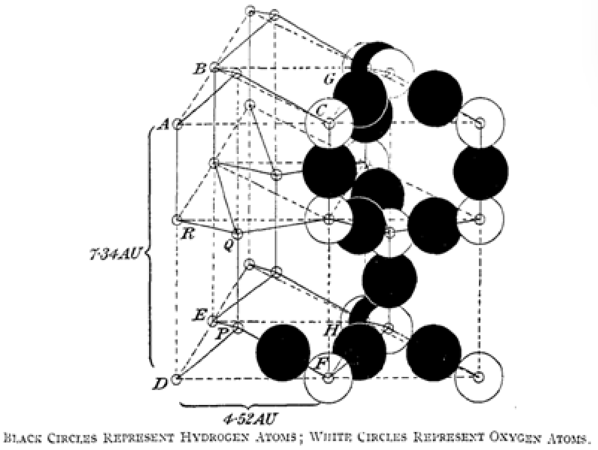


Fig. 3. Hydrogen atoms and oxygen atoms (Bragg, 1921).

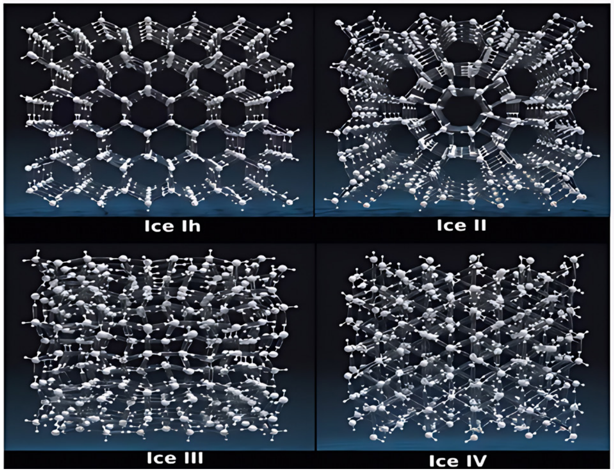


Fig. 4. Ice polymorphs (Himoto, 2022).

The discovery of ice polymorphs and clathrate hydrate

Bragg's hexagonal lattice was only the beginning. As crystallographic techniques advanced, scientists discovered that water could solidify into a bewildering variety of crystalline forms depending on temperature and pressure. These are the polymorphs of ice –multiple structures of the same chemical substance. The ordinary hexagonal form that covers lakes and snowfields is known as Ice Ih (fig. 3), but it is only one member of a growing family. To date, more than twenty distinct phases of ice have been identified, each with unique symmetry and packing. The first new polymorph to be discovered after Ice Ih was Ice II, a denser and more ordered structure found under pressure. Soon after, others followed: Ice III, Ice V, Ice VI, and so forth, each corresponding to specific thermodynamic conditions (fig. 4). These polymorphs are not mere curiosities; their study revealed that the hydrogen-bond network of water is astonishingly versatile, able to rearrange itself into geometries ranging from open hexagonal channels to tightly packed cubic grids. Each form holds different densities, refractive properties, and stabilities [Salzmann 2011].
For scientists, the polymorphs of ice became both a challenge and a key. They challenged experimental technique, because producing and preserving these exotic forms required high-pressure chambers and cryogenic controls. At the same time, they became a key to understanding water's anomalous properties: its density maximum at 4°C, its high heat capacity, and its central role in climate and biology [Huda 2019]. By cataloguing the polymorphs, researchers began to see water not as a simple liquid but as a substance with a rich inner architecture, unfolding across multiple dimensions of phase space. On Earth, the high-pressure polymorphs play a role deep within glaciers and the icy crusts of polar regions. Beyond Earth, they are critical for understanding the geology of icy moons and planets. Jupiter's moon Europa, Saturn's Enceladus, and distant trans-Neptunian bodies all contain ice phases that never occur naturally on the Earth's surface [Fortes 2013]. By knowing the polymorphs, scientists can infer the internal dynamics of distant worlds, estimating whether their icy shells hide liquid oceans beneath. Here again, drawing is central: planetary models often begin as lattice diagrams, scaled upward to the size of moons, translating microscopic structures into macroscopic geology [Ball 2001].
Out of this expanding knowledge emerged one of the most intriguing discoveries: the existence of clathrate hydrates. Unlike ordinary ice, which bonds only water molecules together, clathrate hydrates form cage-like

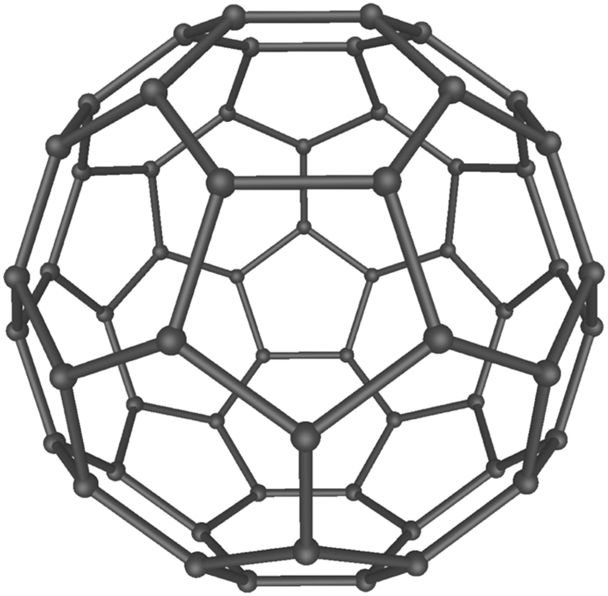


Fig. 5. Molecule of Fullerene, C60 created by Michael Ströck <https://id.wikipedia.org/wiki/Fulerena#/media/Berkas:C60a.png> (accessed 2025, October 21)

Fig. 6 Prof. Bando Takaaki collaborative project to make bamboo shelter that shapes in inspired by Buckminster Fuller's dome [Larasati 2012] <https://investor.id/property/32710/takaaki-bando-jadikan-bambu-hunian-masa-depan> (accessed 2025, October 21)

frameworks that enclose 'guest' molecules such as methane, carbon dioxide, or hydrogen [Sloan 2007]. First observed in the nineteenth century but only systematically studied in the twentieth, these hydrates represented a radical extension of water's versatility. Clathrate hydrates revealed that ice is not just a crystalline solid but also a potential storehouse of gases and energy. Vast deposits of methane hydrates have been found under ocean floors and in permafrost, estimated to contain more carbon than all known fossil fuel reserves combined.

Beyond their practical value, these hydrates fundamentally changed how chemists visualized matter. Unlike standard ice, which repeats a simple pattern, clathrate structures are complex, multi-sided cages–often shaped like twelve-sided balls (dodecahedra). To understand them, scientists had to shift their focus: they stopped drawing mere 'connections' between atoms and began drawing 'volumes' of empty space. This was a crucial turning point. The drawing was no longer just about the solid frame, but about the void inside it. By visualizing this emptiness, scientists could finally see how a solid crystal could act as a container.

From drawing to generative knowledge

The advance of computing transformed the study of ice once again. Where Bragg sketched static lattices, modern scientists now construct digital simulations that capture the dynamic vibration of molecules. A pivotal advancement in this field emerged from Matsumoto's paper, which showed that water's strange behavior–such as expanding upon freezing–arises not from a mixture of two distinct components but from continuous

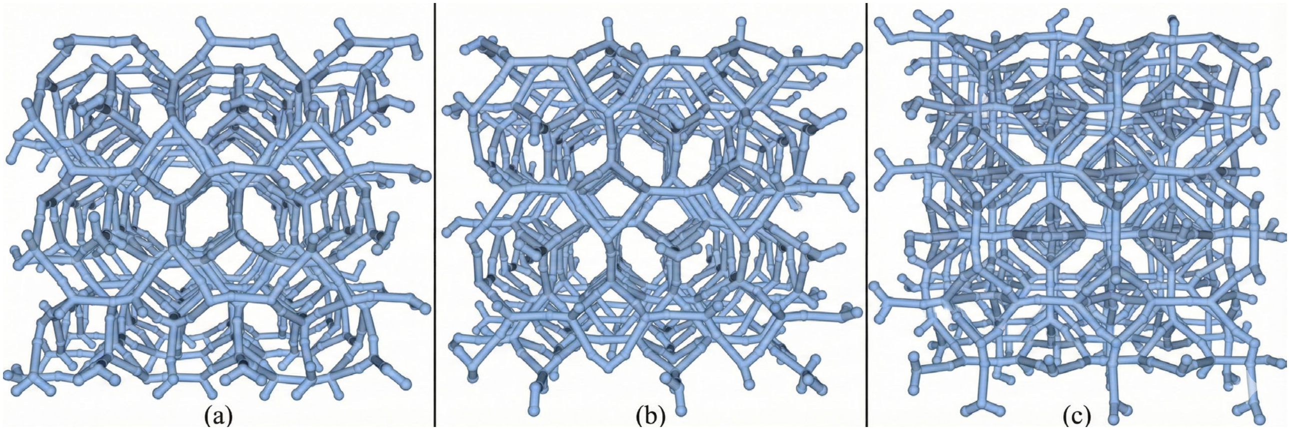


Fig. 7 Views of the compressed Ice VI structure along different crystallographic axes. (a) View along the x-axis. (b) View along the y-axis. (c) View along the z-axis. The light blue framework represents the network of hydrogen-bonded water molecules [1].

adjustments in a single hydrogen-bond network [Matsumoto 2002].
Matsumoto's models revealed the subtle interplay of geometric parameters: hydrogen bond extension drives expansion, while angular distortion produces contraction. These processes, invisible to experiment alone, became visible through molecular animation. The simulation, like the drawing before it, turned abstract measurements into a picture of reality, demonstrating that representation is not only explanatory but generative.
This generative capacity now informs fields far beyond chemistry. In climate science, modeling ice pressure is critical for understanding glacier dynamics; in energy research, hydrates guide the exploration of methane and hydrogen storage; and in planetary science, polymorphs serve as diagnostic markers for subsurface oceans on distant moons [Fortes 2010]. Even in materials science, the cage-like structures of hydrates have inspired the design of porous frameworks such as zeolites and metal-organic frameworks (MOFs). This trajectory –from Bragg's static sketches to Matsumoto's dynamic simulations– proves that drawing functions as a method of inquiry. It transforms abstract patterns into intelligible structures, bridging the gap between the invisible laws of matter and the visible world of design.

From molecular structure to architectural form

The relationship between chemical structure and architectural drawings is made visible through their shared dependence on polyhedral geometry. By translating these crystalline diagrams into design principles, architects can move beyond mere mimicry of shape to apply the performance logic of molecules. This translation is evident in a progression from simple artistic displays to complex structural systems and, ultimately, to metabolic environments.
A particularly illustrative case is the truncated icosahedron, whose geometry underlies the molecular structure of fullerene (C_{60}) (fig. 5). The molecule, commonly known as the Buckyball, was predicted and later synthesized in 1985 by chemists analyzing stellar carbon formations. In architecture, this form has largely been explored through temporary or artistic applications. A prominent example is the Bamboo Shelter Project by Professor Takaaki Bando, which reinterprets the C60 form to create a lightweight, renewable enclosure (fig. 6). While structurally efficient, the application here remains primarily an artistic display –a pavilion that mimics the molecule's closed-cage simplicity rather than its complex interconnectivity. It demonstrates the potential of molecular form but remains at the scale of the object.

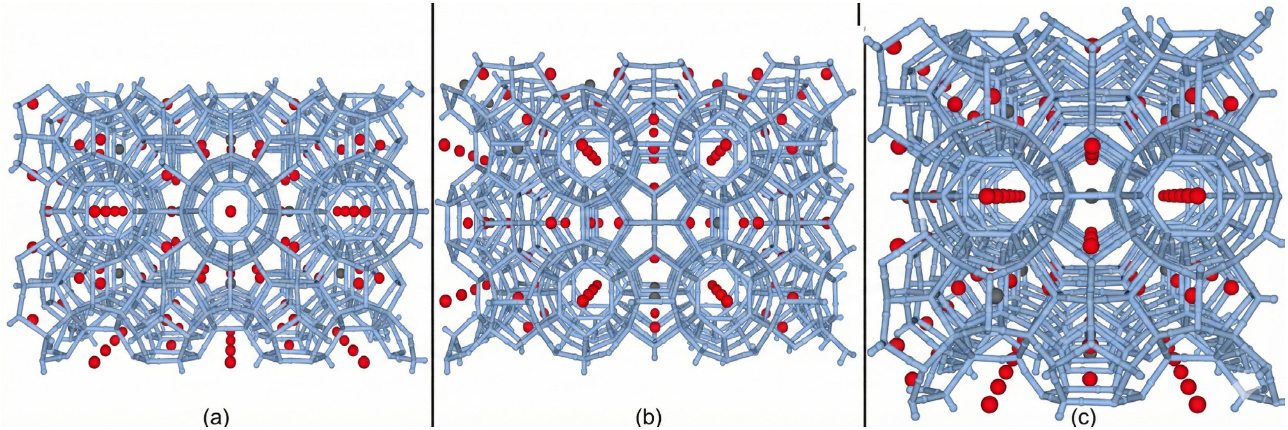


Fig. 8 Views of the CS1 clathrate hydrate crystal structure along different crystallographic axes. (a) View along the x-axis. (b) View along the y-axis. (c) View along the z-axis. The light blue framework represents the host water lattice, and the red spheres indicate the guest molecules encapsulated within the cages. [1]

To move from artistic pavilions to functional infrastructure, we look to the polymorphs of ice. Unlike the simple cage of a fullerene, the high-pressure phases of Ice IV and Ice VI (fig. 7) consist of self-interlocking, catenated networks. These dense lattices offer a blueprint for high-compressive strength modules, making them ideal inspirations for vertical load-bearing systems in skyscrapers. Yet, their intricate, non-repetitive symmetries also hold immense aesthetic potential, suggesting a dual application: they can serve as the engineering logic for a tower's core or as the expressive geometry of its façade. Here, the lattice evolves from a simple shell into a complex, load-bearing framework.
Finally, the chemical structure of Clathrate Hydrates extends this logic into the realm of inhabitation. Scientifically, clathrates (fig. 8) are 'guest-host' structures where a rigid water lattice cages a volatile gas molecule. This molecular architecture mirrors the Metabolist vision of the 1960s, notably realized in Kisho Kurokawa's Nakagin Capsule Tower (1972). Just as the clathrate lattice provides a stable framework for guest molecules, Kurokawa's design distinguishes between a "permanent element" (the concrete shafts) and a "transient element" (the removable capsules) [Lin 2007, p. 515]. This separation allows the building to function as an organic process, theoretically enabling the "metabolic" replacement of units. While clathrate hydrates store methane, these architectural cages store the urban nomad, providing a compact interface that mediates between the individual and the city [Šenk 2019].
Such structural parallels reveal drawing's dual nature as both an epistemic and a generative tool. It visualizes the hidden laws of matter while simultaneously providing a system of constraints that can produce new forms. By translating the structural clarity of crystalline geometry into design parameters, architects adapt the same mathematical discipline that chemists use to describe molecular organization. In this way, the crystalline diagram becomes a shared language of discovery and creation, bridging scales from the molecular to the architectural [Katz 2011; Leonova 2025].

Drawing as an operative tool for design

The act of drawing has long operated at the threshold between knowledge and imagination, serving both science and design as a means of translating invisible structures into visible form. As Rohr [Rohr 2012] observes, drawing is never merely representational, it is a way of

knowing, a process that organizes and makes sense of complexity [Watson 1953]. From botanical illustrations to technical diagrams, drawings have historically functioned as epistemic tools, transforming quantitative data into understandable images. This epistemological dimension resonates with contemporary design, where drawing mediates between molecular geometries and architectural possibilities, revealing unseen orders of matter and offering new models for creative practice.
This bridging role is historically evident in the evolution of technical drawing. Leonardo's anatomical sketches and Monge's descriptive geometry each illustrate how scientific measurement was converted into universal codes for spatial reasoning. Such methods established a lineage in which drawing became a structured methodology: a practice capable of translating invisible structures into workable forms for engineers, architects, and designers. Today's computational environments extend this trajectory, offering parametric and generative systems that allow designers to manipulate geometries inspired by scientific discoveries, integrating empirical precision with formal invention [Carpo 2011].
The study of ice polymorphism demonstrates this bridge in a striking way. Bragg's lattice diagrams, once intended to explain why ice floats, now serve as exemplary models of how molecular order can inspire structural and spatial thinking. The discovery that water solidifies into multiple crystalline polymorphs, each with distinct symmetries and densities, suggests a repertoire of geometrical archetypes. Salzmann's review of the 19 known polymorphs of ice reveals a library of structures –hexagonal, cubic, tetragonal– that can be reinterpreted not only as scientific data but also as design grammars. For designers, these crystalline patterns provide a kind of "material logic" [Oxman 2010, p. 102], an abstract rule-set through which new formal and structural possibilities can be generated. This approach reflects a broader theoretical shift in design thinking, in which geometry is no longer seen only as a representational device but as generative logic. As Pérez-Gómez argues, architectural drawing has always embodied a 'poetic disclosure' of hidden order, bridging abstract ratios with material presence [Pérez-Gómez, 2006]. Similarly, the translation of crystallographic data into design language is not simply imitation but interpretation: an act of discovering new spatial logics through molecular analogies. Here, drawing becomes a medium of dialogue between chemistry and design, opening possibilities for biomimetic materials, adaptive structures, and architectural systems rooted in the architectures of matter itself.
In this way, the invisible geometries of ice polymorphs do more than explain water's physical behavior –they expand the imagination of design. Through drawing, molecular architectures are made perceptible and operative, transforming scientific discovery into a source of formal invention. The epistemic bridge that drawing builds between chemistry and design thus affirms its dual role: as a method of inquiry into hidden orders of nature, and as a generative practice for shaping new cultural and material realities.

Conclusion

Drawing serves as a critical epistemological tool that bridges the abstract, invisible world of chemistry with the tangible realm of design. By translating data from tools like X-ray diffraction and computational models into apprehensible forms, it renders the 'invisible architecture of matter' operative for scientist and designers. Ultimately, drawing allows us not only to visualize hidden geometries but to harness their potential as knowledge-inducing patterns, creating new spatial logics rooted in the fundamental laws of matter.

Notes

[1] The image of clathrate hydrate was generated using the molecular simulation software GenIce [Matsumoto 2018].

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The Aesthetics of Logic.
Form, Structure, and Design

Between Structural Theory and Construction Practice: The Role of Drawing in Pier Luigi Nervi's Ribbed Floor Slabs

Francesco Romeo

Introduction

Among the many structural solutions that characterize the work of Pier Luigi Nervi (1891-1979), the leading Italian figure in twentieth-century structural engineering, the ribbed floor slabs arranged according to the isostatic lines of bending represent an emblematic outcome of his synthesis of structural logic, constructive efficiency, and expressive quality. In this solution more than in others, drawing plays a decisive role in translating the static principle into built architecture, acting as a critical instrument of selection: through drawing, among the multiple configurations referable to a single guiding principle, those capable of combining constructive correctness with expressive effectiveness are identified.

In the design of ribbed slabs, as in his broader activity as both designer and builder, Nervi makes an exceptionally conscious use of drawing and photography, going well beyond the conventional employment of these tools by structural engineers. This attention is fully consistent with his *modus operandi*, rooted in his dual role as conceiver and executor. On the one hand, two-dimensional hand drawing is crucial not only for the geometric and constructive control of structural and architectural solutions, but also for their communication to the client. In this regard, Nervi observes: "The graphic presentation of an architectural idea is a difficult and imperfect matter. Drawing is always a very unfaithful interpreter of architectural reality; only the designer is able

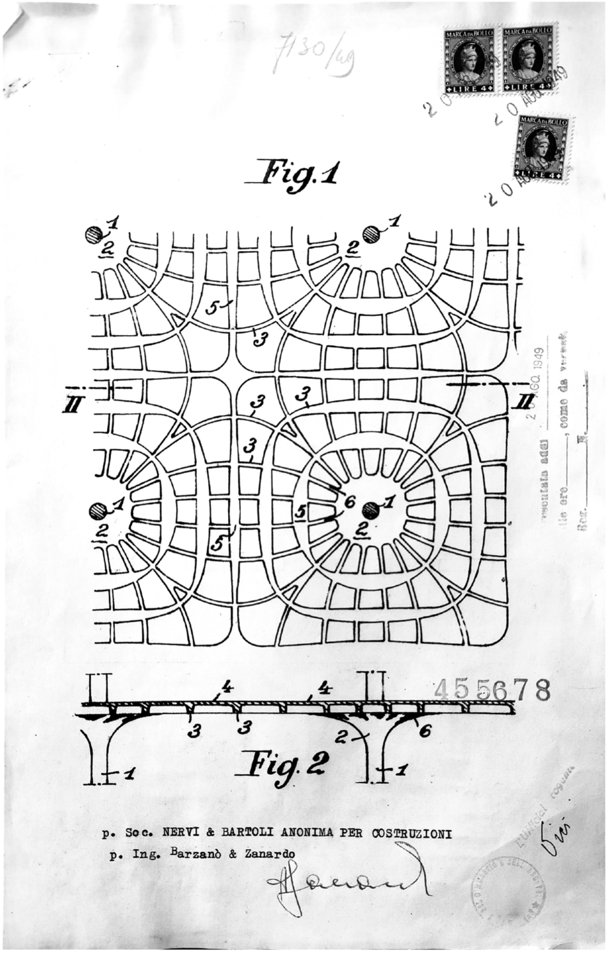
This article was written upon invitation to frame the topic, not submitted to anonymous review, published under the editorial director's responsibility.

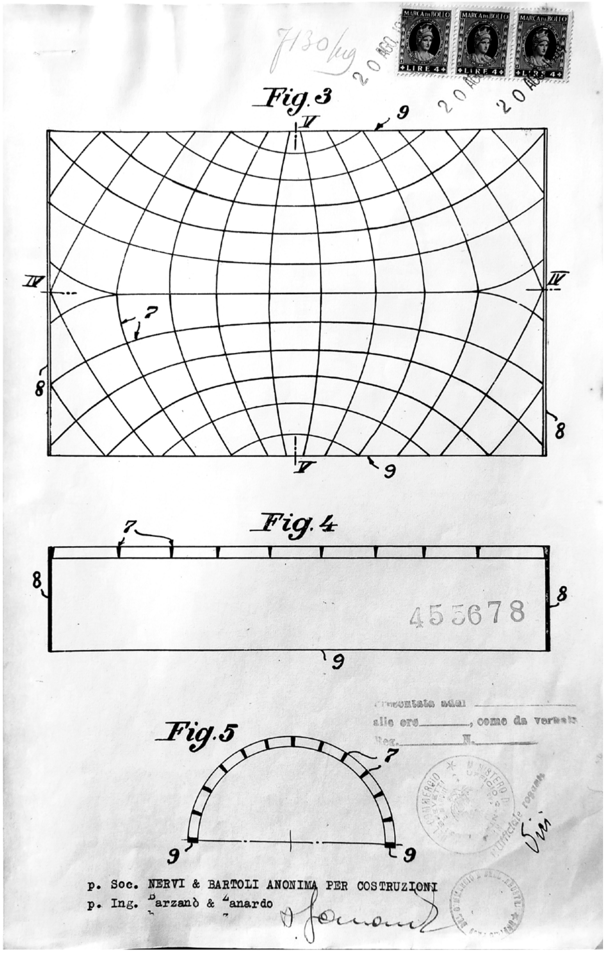
to materialize it through mental procedures, comparisons, or references that are entirely personal and not communicable. [...] One should therefore consider how difficult an architectural choice is, when to all the deficiencies of graphic representation are added the problem of scale [...] and the concern arising from the moral and material importance that is always associated with a building" [Nervi 1945].
On the other hand, photography assumes a central role for its communicative impact and for Nervi's international recognition as a designer, functioning both as a tool for documenting the construction process and as a visual archive for future work. As with many of Nervi's innovations, the ribbed floor slabs based on isostatic lines of bending are accompanied by a corpus of drawings and photographs that extends beyond the design phase and the completed work, documenting the entire construction process and providing a graphic record rich in meaning.
To understand the emergence, at the end of the 1940s, of ribbed floor slabs laid out according to isostatic lines of bending within Nervi's design vocabulary, it is necessary to consider briefly the multiple factors that shaped their genesis: Nervi's design philosophy, the technical-scientific context, the contribution of engineer Aldo Arcangeli (1916-2000), and the constructive possibilities afforded by the historical period [Iori 2012; Halpern, Billington, Adriaenssens 2013; Neri 2014; Gargiani, Bologna 2016; Lembo 2026].
As early as 1945, in *Scienza o Arte del Costruire?*, reflecting on the relationship between architectural form and the potential of new materials, Nervi responds to the fear of a spiritual impoverishment brought about by technology in the following terms: "Approaching with modesty the mysterious laws of nature, striving to interpret them, and that 'commanding by obeying' which is the only way to place their majestic eternity at the service of our limited and contingent purposes, contains a profound poetry, capable of being translated into forms of high aesthetic and artistic expressiveness" [Nervi 1945].
From this perspective, structural form is never arbitrary, but derives from an understanding of static mechanisms and from their correct interpretation. This principle finds a more explicitly operative formulation in 1951: "I believe I can affirm that, for reinforced-concrete floor slabs with uniformly distributed loads, the standard solution has already been identified. It consists in the arrangement of the ribs along the isostatic lines of the principal moments: a layout proposed and theoretically studied by one of my collaborators, engineer Aldo Arcangeli, and made concretely feasible by a particular construction process of my own devising, which allows ribs of any shape to be executed without appreciable variations in cost. The isostatics are in fact the preferential lines of force flow within a solid, and concentrating the resistant material along them guarantees maximum structural efficiency. These lines depend solely on the system of acting forces, and our only possibility is to discover and exploit them, certainly not to modify them" [Nervi 1951].
Between the theoretical statement of 1945 and the applied formulation of 1951 lie the patents filed in 1949, from which the translation of the principle of isostatic lines into a construction system effectively begins.

The 1949 patents

Patent no. 455678, entitled *Improvement in the construction of slabs, vaults, domes, wall-beams and load-bearing structures in general, of two or three dimensions, with the arrangement of resisting ribs along the isostatic lines of bending moments or normal stresses*, was filed on 23 July 1949 by the company Società Ing. Nervi & Bartoli in the name of engineer Aldo Arcangeli. At that time, Arcangeli collaborated closely with Pier Luigi Nervi both as an employee of the Nervi & Bartoli construction firm and as an assistant at the Faculty of Architecture of the University of Rome La Sapienza. The patent summarizes the theory of isostatic lines, identifies its possible fields of application, and emphasizes the economic advantages deriving from the concentration of resisting material along these lines [Arcangeli 1949] (fig. 1).
On the same day, 23 July 1949, Pier Luigi Nervi filed patent no. 455750, the third supplementary patent to the main patent no. 406296 of 15 April 1943, entitled *Improvement in the construction of reinforced-concrete slabs, plates and other cementitious structures*. This supplementary patent concerns a specific application of the construction method described in the main patent and in the two previous supplements, relating to the preparation of ferrocement formwork and moulds for casting slabs, columns, and reinforced-concrete structures, as an alternative to traditional timber formwork. As explicitly stated in the patent text, although the system is illustrated with reference to slabs with intersecting ribs, it is independent of the geometry of the ribs, which may be straight or curved and arranged in one or more directions according to structural requirements, without altering the conceptual or constructive substance of the method [Nervi 1949] (fig. 2).

Fig. 1. Patent n. 455678, 23 July 1949, Società Nervi & Bartoli, inventor A. Arcangeli (Archivio Centrale dello Stato).





In summary, while the patent filed in Arcangeli's name sets out the theoretical foundation of isostatic lines, identifies their possible applications, and highlights their economic advantages, Nervi's supplementary patent provides an effective construction method for their realization, making both the monolithic character of the finished structure and formal freedom practically achievable.

Theoretical context

In order to clarify the scientific foundations of the proposed innovation, it is appropriate to briefly recall some principles of solid mechanics that constitute its theoretical premises.
In solid mechanics, the state of stress induced by mechanical actions within a body is described by the Cauchy stress tensor, which depends on the point considered and on the normal to the plane on which the stress acts. When referred to an intrinsic coordinate system, each plane orientation is associated with one normal component and two tangential components. The planes on which purely normal stresses act are known as principal planes; the mutually orthogonal normals defining them constitute the principal directions. The envelope of the principal directions at each point of the body defines three mutually orthogonal families of curves, known as isostatic lines. Along these lines, only axial stresses (tensile or compressive) act, attaining extremal values with respect to the normal stresses acting on the pencil of planes passing through the point.
When one dimension of the body is much smaller than the other two, the problem may be referred to the mid-surface (thin plates and shells), on which the isostatic lines reduce to two orthogonal families of curves. Similarly, for two-dimensional bodies subjected to bending –such as plates and shells in bending-dominated regimes– the previous concepts remain valid provided that normal and tangential stresses are replaced by bending and twisting moments. This leads to the definition of principal moments and their trajectories, or bending isostatic lines, along which pure bending acts in the absence of torsion. Their configuration depends on the geometry of the body, the loading conditions, and the nature and arrangement of the restraints.
The tracing of bending isostatic lines is governed by a first-order differential equation, expressed as a function of bending and twisting moments, which, within classical thin-plate theory, are derived from the integration of the biharmonic equation of the elastic surface. Exact solutions, however, are

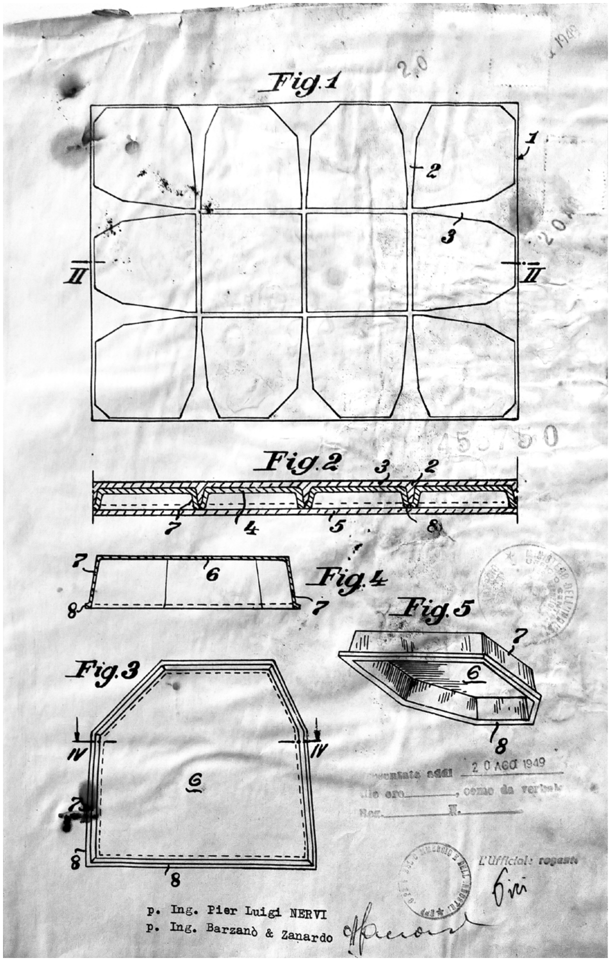
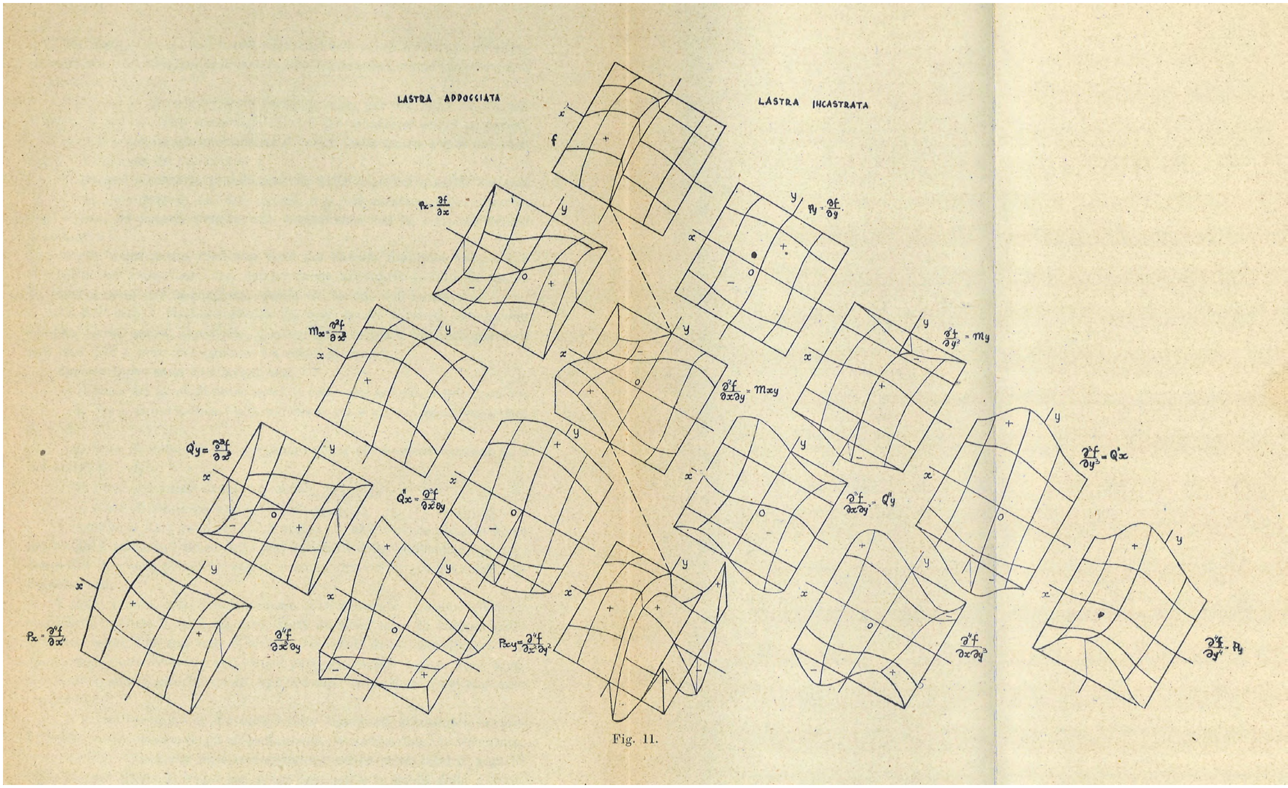


Fig. 2. Patent n. 455750, 23 July 1949, Pier Luigi Nervi (Archivio Centrale dello Stato).

Fig. 3. Surfaces of the derivatives of function 'f', plate vertical displacement. (Kambo 1944, p. 34).



limited to a small number of canonical cases. The principal methods available in the postwar period provided solutions only for simple configurations commonly encountered in practice [Belluzzi 1947], expressed in double trigonometric series (Navier), simple hyperbolic series (Lévy-Estanave), or through finite-difference methods (Nielsen, Marcus). These were complemented by attempts to reduce the analytical burden, such as Kambo's method of arbitrary solids [Kambo 1944], according to which bending isostatic lines may be derived from the surfaces of the third row in figure 3 and from the 'curvature circle' (Mohr's circle).
Arcangeli could therefore rely on a limited set of analytical solutions and on tabulated numerical results for selected canonical cases; his handwritten calculation notes reveal a familiarity with the solution expressed in simple hyperbolic series presented in Nadai's treatise [Nadai 1925] [1]. Figure 4 shows sketches by Aldo Arcangeli referring to the case of a plate simply supported along all edges and clamped at the four corners [Lembo 2026].
In response to the limitations of theoretical analysis –already highlighted in the early twentieth century by the groundbreaking design possibilities offered by reinforced concrete– many engineers systematically turned to experimental methods. This approach, which places Nervi alongside key figures of twentieth-century structural architecture [Chiorino 2010], took concrete form in his collaboration with the *Laboratorio Prove Modelli e Costruzioni*, founded by Arturo Danusso at the Politecnico di Milano.
In the seventh chapter of *Costruire correttamente* [1955], Nervi emphasizes the superiority of experimental methods for understanding the actual static behaviour of load-bearing systems, focusing in particular on strain-gauge and photoelastic techniques. The theoretical framework within which these methods operate is clarified by Enrico Volterra, who as early as 1930 introduced photoelasticity as a means of "seeing what manifests itself inside a structure subjected to external forces", likening it to the use of Roentgen rays in medicine [Volterra 1930]. It is plausible that Nervi's interest in these methods was also fostered by the applications carried out by Danusso together with his pupil Guido Oberti from the early 1930s onward [Danusso 1932], perceiving in them, as he himself writes, "the beauty and poetry of this transformation of states of stress into plays of light […]" [Nervi 1955]. Nervi's interest in photoelasticity, documented by images preserved in the Studio Nervi archives and published in *Costruire correttamente*, is to be understood within this context.

Fig. 4. Drawings of square plate flexural isostatic lines for different boundary conditions: top, simply supported sides; bottom, simply supported corners Archivio Arcangeli, Roma, Fascicolo A 237.

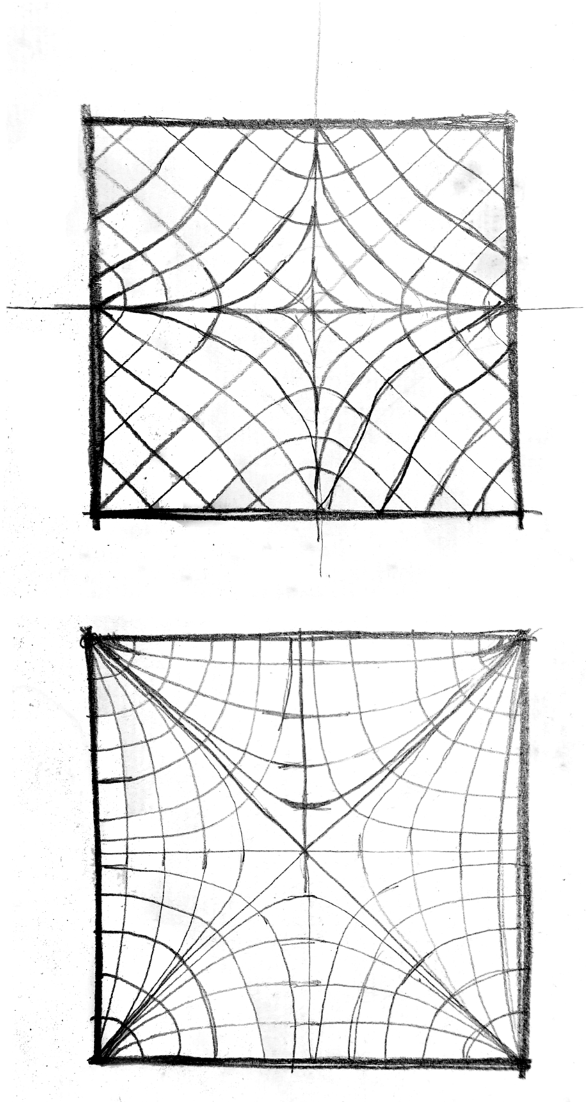
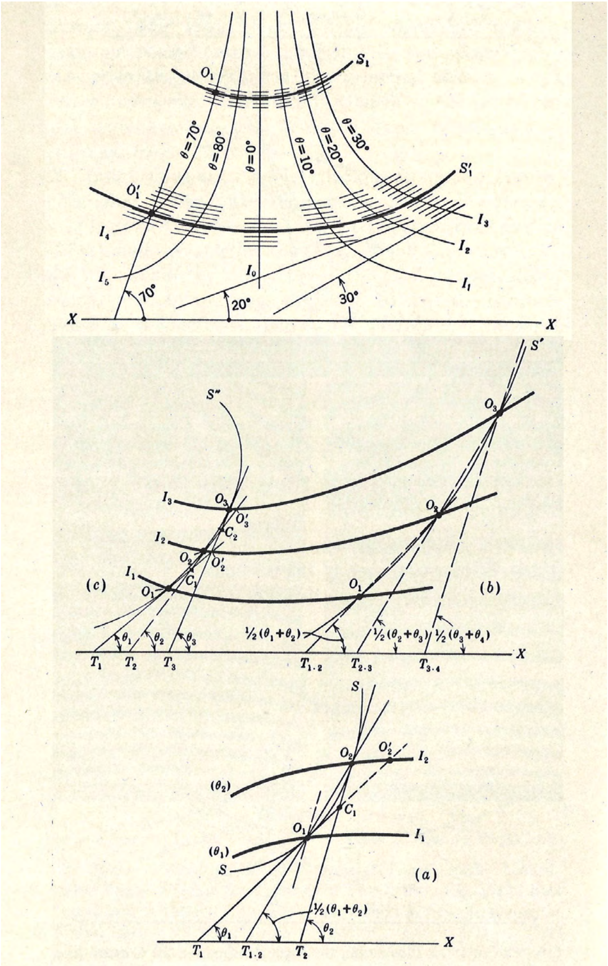
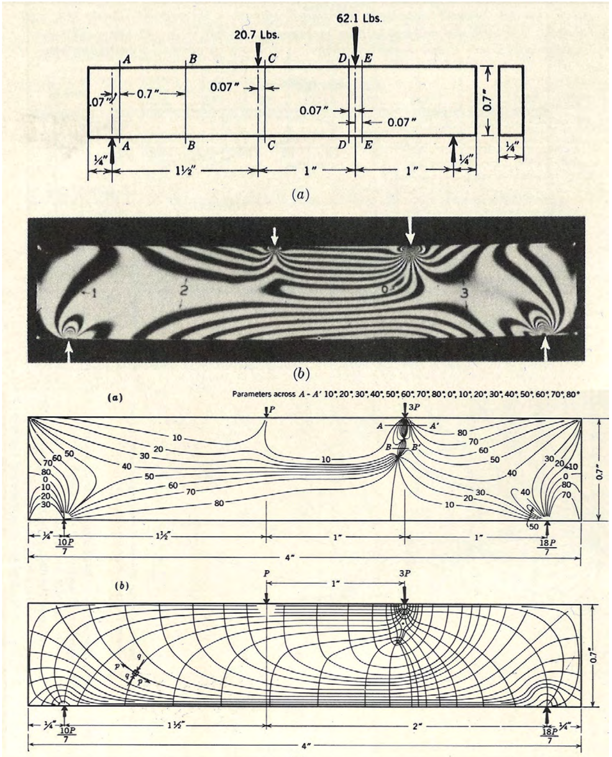


Fig. 5. Alternative schematic methods for deriving isostatic lines from isoclines: Frocht M. 1941, pp. 199, 200.

Fig. 6. Experimental setup, photoelastic analysis, isoclines and isostatic lines: Frocht 1941, pp. 258, 259.





The method allows for an immediate visual representation of the internal stress state of a body: the network of isoclines provides the orientation of the principal stresses, while that of the isochromatics conveys their relative intensity. From photographed isoclines, the layout of the isostatic lines can be reconstructed through graphic procedures (figs. 5, 6) [2]; the determination of the individual principal stresses, by contrast, requires integrative methods such as Mesnager's method or graphical integration based on Maxwell's formulas.
Within this framework, experimentation does not so much constitute a direct operational design tool [3] as a cognitive device capable of orienting the understanding of stress flows and of nourishing, on a graphical level, the construction of structural schemes consistent with the actual behaviour of structures.

The application context

The proposal of ribbed slabs arranged according to bending isostatic lines is embedded within the broader development of reinforced concrete slabs, which began as early as the late nineteenth century. From the Monier slab (1869) to the Hennebique systems with primary and secondary ribs (1898), and further to the mushroom-type slabs developed by Turner (1907) and Maillart (1908), the evolution of reinforced concrete slabs was accompanied by an intense production of patents aimed at transforming pioneering experiments into consolidated construction practices. Although structurally effective, these early solutions soon revealed limitations related to self-weight, material consumption, and acoustic performance.
Research initially focused on reducing slab thickness through the densification of secondary ribs, and subsequently on replacing concrete in the tensile zones with lighter materials, such as hollow clay units. Systems with lightweight infill elements placed below the neutral axis, between parallel or orthogonally intersecting ribs, thus became widespread, progressively supplanting reinforced concrete slabs with exposed ribs. Among the double-joist systems, those developed by Bollinger (1902) and Danusso (1911) are particularly noteworthy.
It is within this context that Nervi's professional career began. In 1913, he joined the Società Anonima per Costruzioni Cementizie of Professor Attilio Muggia (1861-1936), holder of the Hennebique patent concession for Emilia-Romagna and the Marche. Technical innovation immediately became a defining feature of his work. The constructional refinement described in the 1949 supplementary patent represents the outcome of a long trajectory of experimentation [Greco 2008]. Within this framework, structural drawing assumes the role of a control instrument for an advanced construction process, in which prefabrication makes it possible to achieve levels of technical complexity and formal refinement that would have been difficult to attain through cast-in-place concrete and traditional timber formwork. The 1949 supplementary patent, for example, describes a system of ferrocement formwork arranged on a lowering and sliding scaffold, allowing for formwork removal and progressive reuse of the moulds in the construction of large-span slabs composed of repetitive bays, thereby optimizing construction time, costs, and execution quality.

Fig. 7. Plan and section of the Lanificio Gatti basement floor: Lembo 2026, p. 138.

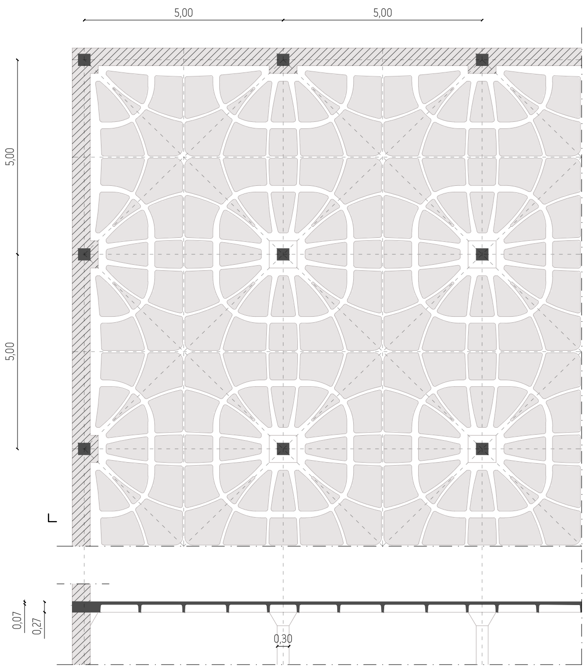
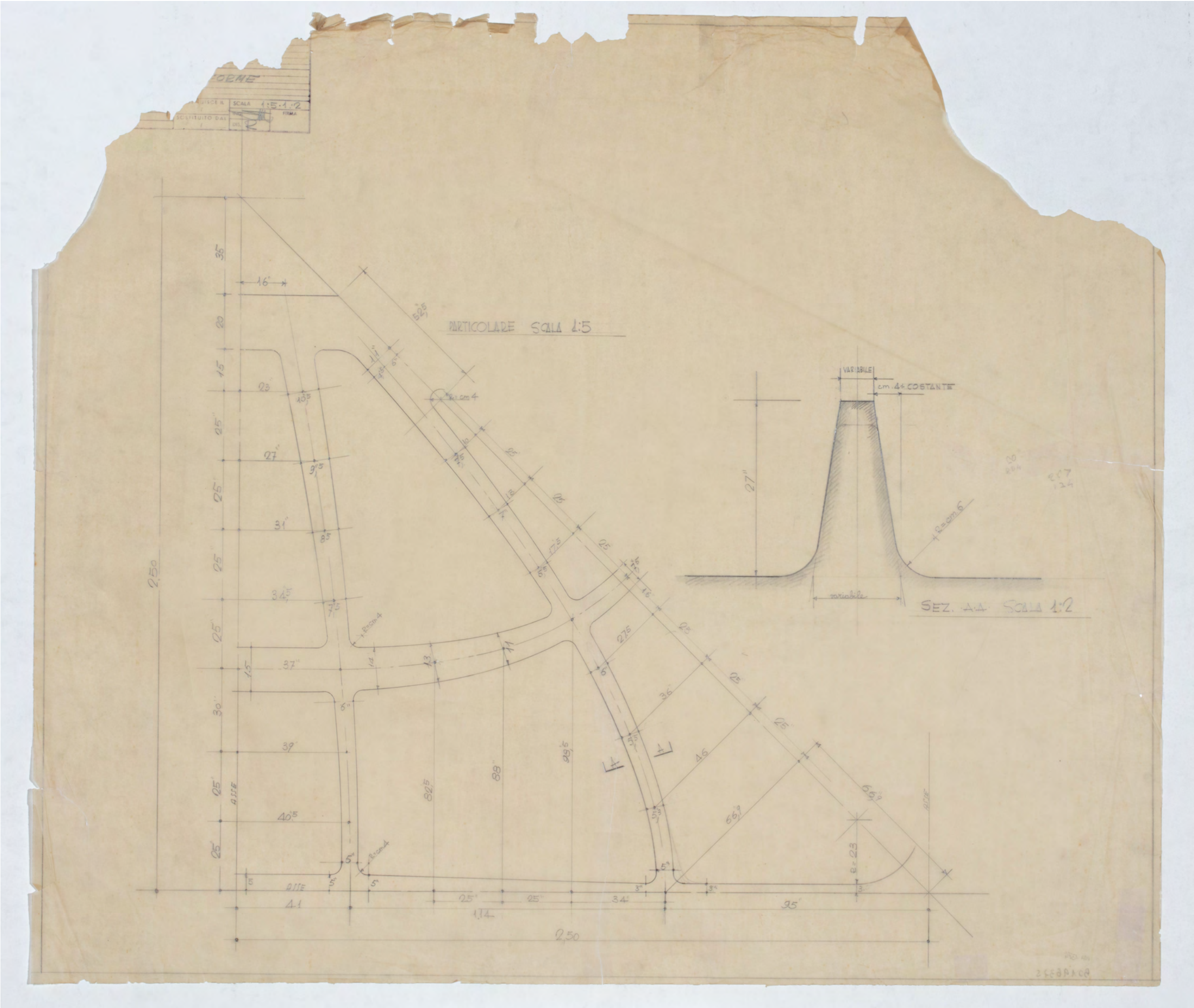


Fig. 8. Tracking of the axes and thicknesses of the ribs of the Lanificio Gatti basement floor (Parma, CSAC).



Projects and built works

From the very first applications of the solutions patented in 1949, it became evident that a strict adherence to the isostatic bending lines was impossible. In the transition from a continuous plate to a ribbed floor composed of a slab and ribs, the geometry of the original plate is necessarily altered, and with it the arrangement of the isostatic lines. In addition, the boundary conditions may vary between the construction phases and the final configuration. Consequently, as noted by Mario Desideri, regardless of the accuracy with which these trajectories are determined, the slabs are always ribbed slabs 'inspired' by the isostatic bending lines rather than an exact transposition of them [Castelli, Del Monaco 2011]. This awareness does not hinder the adoption of this solution, initially proposed as a variant of the traditional orthogonal rectilinear grid and progressively established as an independent choice, eventually requested by clients.
Over approximately thirty years, from the late 1940s to the late 1970s, Pier Luigi Nervi and the Nervi Studio designed and built numerous ribbed floor slabs that, in various ways, can be traced back to the isostatic bending lines. These structures refer to slabs of very different sizes, shapes, boundary conditions, and loadings, for which the ideal isostatic configurations assume highly variable geometries. Beyond the designer's formal intentions, the exact identification of such lines was limited both by the theoretical knowledge and computational tools available and by practical construction constraints. The proposed solutions, whether realized or remaining at the design stage, can therefore be interpreted as compromises between theoretically infinite geometries and construction constraints, resulting in a wide repertoire of variations on a theme, reflected in the variety of drawings required for their definition and execution. A measure of the 'distance' between the ideal isostatic lines and the ribs as actually built can be effectively assessed through the magnitude of torsional moments [Lembo, Bologna, Romeo 2024].
Once the configuration of the ribs was determined, the design of reinforcement for bending and shear was carried out by considering each rib as straight, with a span equal to the curve's development and semi-fixed end restraints, neglecting torsional effects, which were counteracted by the intersecting ribs. Loads, calculated according to influence areas, were conservatively assumed to be concentrated at the intersection points.

Fig. 9. Reinforcement of the side panels of the floor of the Lanificio Gatti (Parma, CSAC).

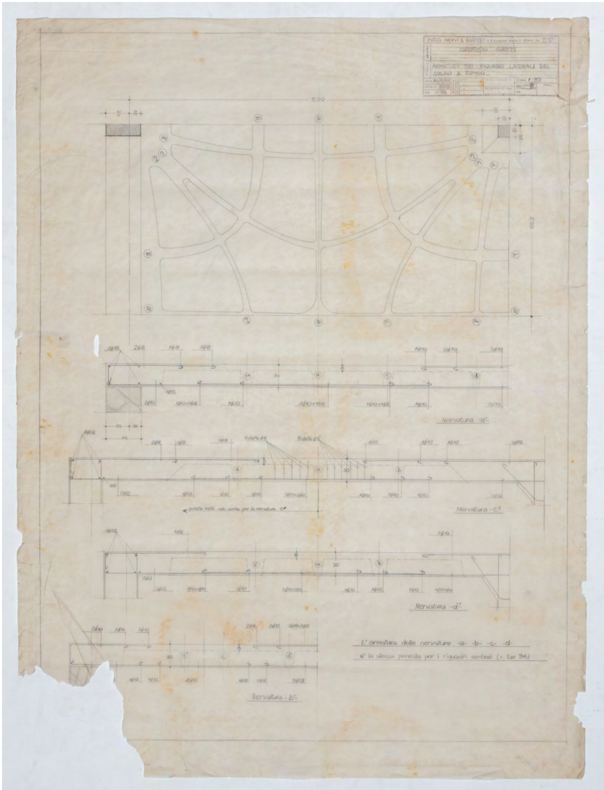
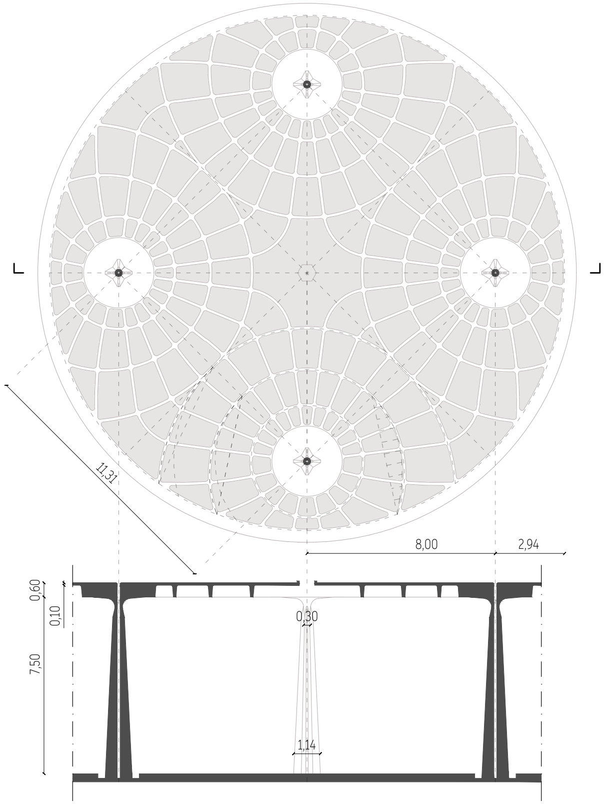


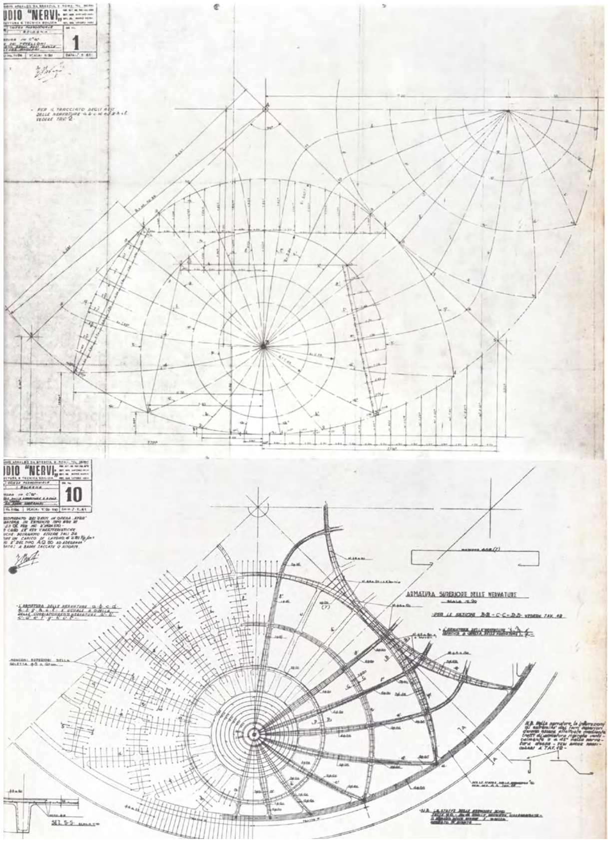
Fig. 10. Close-up photograph of the ribs of the ceiling of the Lanificio Gatti (photo @ Matteo Cirenei).

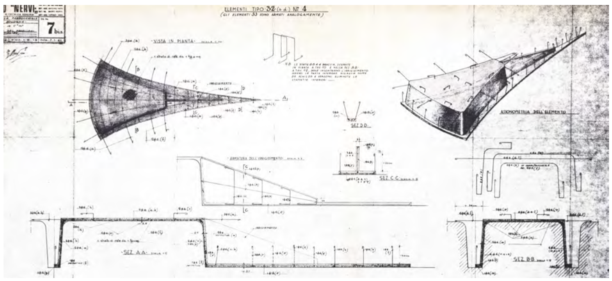
Fig. 11. Plan and section of the roof of the church Cuore Immacolato di Maria in Borgo Panigale: Lembo 2026, p. 155.

Fig. 12. Tracking of the axes and reinforcement of the ribs of the roof of the church Cuore Immacolato di Maria in Borgo Panigale: Nervi 1961.

Fig. 13. Roof of the church Cuore Immacolato di Maria in Borgo Panigale: ferrocement 'tavelloni' (type 32): Nervi, Vaccaro 1961.



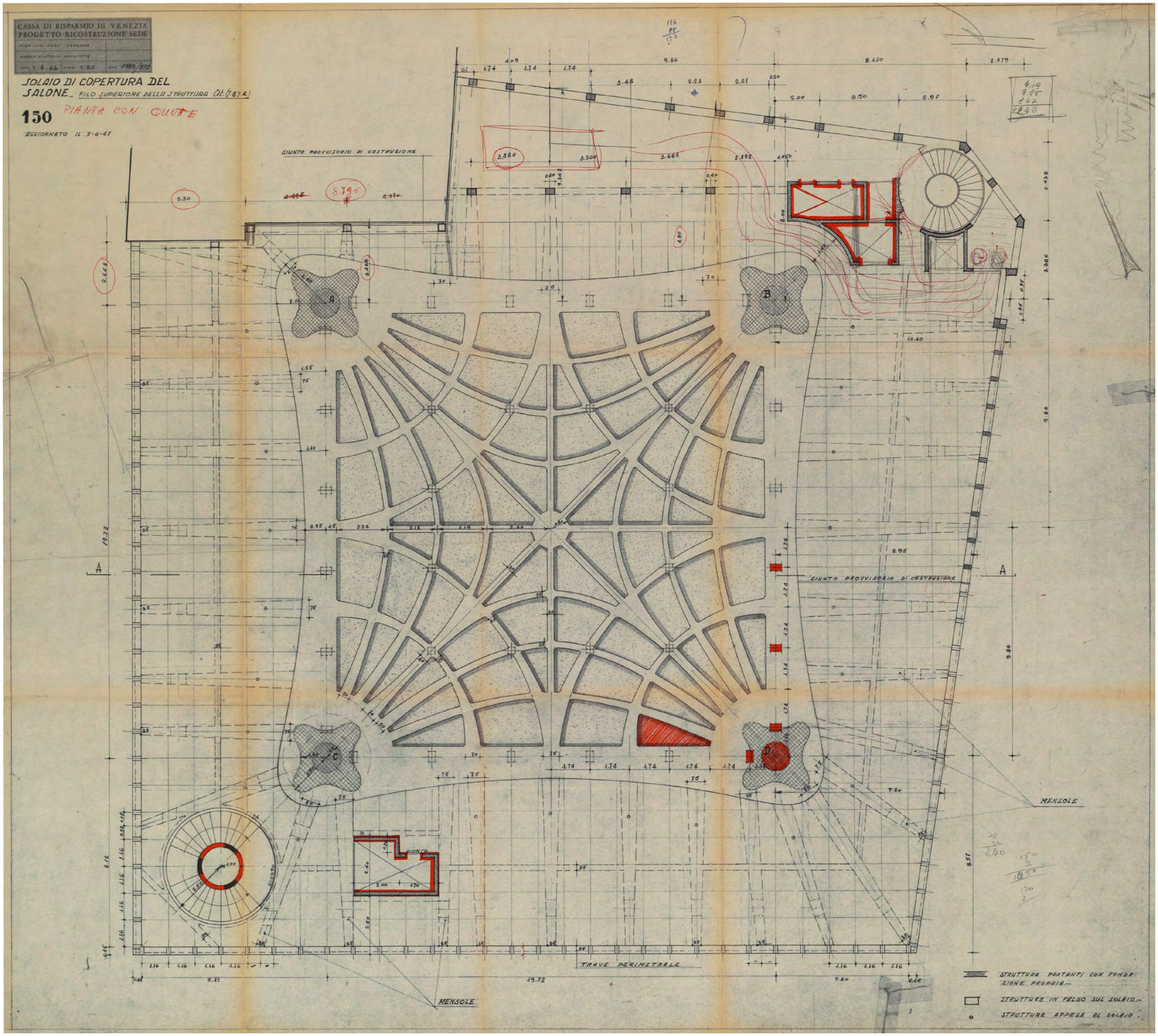




The first applications using ferrocement formwork date to the early 1950s: the Manifattura Tabacchi in Rome (1951), with a central square bay and a lateral rectangular one, and the unbuilt variant of the slab on a rectangular grid at the Magazzino ballette of the Manifattura Tabacchi in Bologna. The same period also saw the Lanificio Gatti (1951-1953), designed with Carlo Cestelli Guidi (1906-1995), featuring the basement slab based on a 5 × 5 m square grid, repeated over 6 × 15 bays (fig. 7).
The design of the ferrocement formwork, together with the corresponding template shown in figure 8, refers to the minimum module, which, due to double symmetry, reduces to an isosceles triangle equal to one-eighth of the square. The formworks corresponding to a bay framed by four columns are mounted on mobile scaffolding, following a technique previously tested for the slab at the Magazzino ballette. The plan layout of the ribs is partly derived from the square slab with central restraints and partly from the slab supported at its four corners, while the variable cross-section follows the distribution of the internal forces [Lembo 2026]. As shown in figure 9, the ribs are reinforced for positive bending moments at midspan and negative moments near the alignments between the columns, where starter bars ensure continuity between adjacent spans (fig. 10). These initial experiences were followed by the trapezoidal canopy at the north entrance of the UNESCO Secretariat (1952-1958), executed with timber formwork.
Among the numerous subsequent works, the circular roof supported by four columns at the Church of the Cuore Immacolato di Maria in Borgo Panigale (1957-1962), designed in collaboration with Giuseppe Vaccaro (1896-1970) (fig. 11), stands out for its geometry. For this roof, with a radius of 11 m, 59 negative mould were produced on the ground using masonry blocks finished externally with plaster (fig. 12); these moulds, corresponding to a single quadrant of the roof, were then used to cast the ferrocement '*tavelloni*' (fig. 13), whose execution quality defines the intrados of the roof (fig. 14).

Fig. 14 Photograph of the underside of the roof of the church Cuore Immacolato di Maria in Borgo Panigale (photo @ Matteo Cirenei).

Fig. 15. Roof covering the hall of the Cassa di Risparmio di Venezia (Parma, CSAC).



Other significant works followed in the 1960s: the perimeter slab composed of trapezoidal panels at the Palazzo dello Sport in Rome (1958-1960), the square-grid slab of the first mezzanine of the Palazzo del Lavoro in Turin (1959-1961), and the slab of the headquarters of the Cassa di Risparmio in Venice (1963-1972) (fig. 15). For the latter, of particular structural relevance due to its size and loading, an experimental investigation was carried out at ISMES (Istituto Sperimentale Modelli e Strutture - Experimental Institute for Models and Structures) in Bergamo on a 1:25 scale model, confirming the conservative approach adopted in the manual calculations.
Alongside these works, a series of projects followed in which the ribs, while maintaining a curvilinear layout, progressively lose reference to the flexural isostatic lines and the genuine role of 'deep decoration' [Rappaport 2006]. This occurs both geometrically, with the orthogonality between the two families of curves being violated (projects for the Cultural Center in Tripoli, the Sports Center in Kuwait, the MLC Center tower in Sydney, and the branch of the Bank of Italy in Cosenza), and structurally, when boundary conditions are disregarded or when the slab is reduced to a mere ceiling, as in the case of the Aula delle Udienze Pontificie in the Vatican (1963-1971).

Conclusions

Ribbed slabs based on flexural isostatic lines demonstrate how drawing can translate theoretical principles into buildable and expressive solutions. The geometry of the ribs emerges from the interplay between scientific rigor and a visual reading of force flows, which informs the form. Although the ideal trajectories are never followed rigidly, drawing makes static intuitions operative and allows complex solutions to be controlled. In Nervi's work, structural form is thus shaped through a cognitive process in which theory, vision, and construction converge, establishing drawing as a central instrument of design.

Notes

[1] It is interesting to note that Arcangeli's notes, alongside the analytical series solution for determining the bending and torsional moments of the square slab in the mid-span, there is an indication for the approximate calculation of negative moments for mushroom-shaped floors in the area adjacent to the pillars, which considers a circular plate with a radius equal to 1/5 of the side loaded with the distributed load and an upward reaction at the centre: Nadai 1925.

[2] To determine isostatic lines, graphical procedures based on isoclines are used, which are equivalent to the graphical solution of differential equations starting from the values of the derivatives.

[3] Nervi used the photoelastic method in 1965 for the Motta Grill project in Limena to deduce the stress state in the large wall beams characterised by 13 octagonal openings of varying sizes: Neri 2014.

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Structure and Expression at Gut Garkau: Hugo Häring's Artisanal Vision

Francisco Cotallo Blanco, Jesús de los Ojos, Jairo Rodríguez

Abstract

Between 1922 and 1926, Hugo Häring designed and built part of the Gut Garkau agricultural complex, located on the southern shore of Lake Pönitzer See. This work is a clear example of functionalist expressionism with vernacular influences, inspired by ideas of Hans Poelzig and later developed by Bruno Taut and Erich Mendelsohn. Häring claimed that the form of the building should come from its function, without imposing preconceived forms, similar to how a living organism functions. When designing the farm, he analyzed in detail the agricultural culture, including daily tasks, the movement of animals and the distribution of industrial machinery, adapting the architecture to these needs. Its architectural expression responds to functional demands, using materials and structures that dialogued with the natural environment. From his project, the barn, stable and an annex building were built around 1924, while other proposals for the horse stable and pigsty remained on paper. The barn, the most prominent part, features an arched roof in the form of a light vault, with a wooden structure formed by a three-dimensional mesh of diamonds, based on the Zollinger system. The study seeks to show how Häring achieved a clear formal expression that reflects the function for which the building was conceived.

Keywords: structure, Gut Garkau, Hugo Häring, functionality, drawing.

Introduction

In May 1922 Hugo Häring wrote in a letter: "an enthusiastic customer has indicated that he needs a farm". This is what Otto Birtner did, a farmer who had learnt about Häring's project for the *Friedrichstraße* skyscraper published by the critic Adolf Behne in the *Hochhaus Heft supplement* of the magazine *Wendingen* in May 1923, was impressed by the architect's work. Birtner owned land in the village of Garkau on the southern shore of Lake Pönitzeer See (Ostholstein, Germany) and was the promoter of the well-known Gut Garkau Farm, Häring's masterpiece. The project began in 1922 with a initial sketch of the extension of the preexisting house and concluded in 1926 with the project for the hostel building: Strohhaus-Pferde-Schweinestall. Finally, only the stable, the barn and annex of Häring's original project were built, in 1924. The rest of the projects for the house and the connection piece between the stable and the barn were never materialized. In Garkau, the author proposed a reformulation of architecture based on his formal theories, seeking to make it emerge in a naturally happen from the specific functions of each space, being intimately linked to structural system.

State of the art

Since the end of the twentieth century, researches on Häring's work have been nourished by new contributions, which are mainly focused on the analysis of his

conception processes, as we can appreciate *Impegno nella Ricerca orgánica* [Bucciarelli 1980]; and others, such as *Il segreto della forma: storia e teoría der Neue beuen / Hugo Häring* [Polano 1984], which delve, among other issues, into the theories that nourish philosophically and formally his work. Critics such as Kenneth Frampton and Reyner Banham, in their respective books, *Critical History of Modern Architecture* [Frampton, 1987] and *Theory and Design in the First Machine Age* [Banham, 1985], also devote specific texts to Gut Garkau's Farm.
In addition, in 2025, 25 years after the last exhibition dedicated to the architect at the Berlin Academy of Arts, the focus has been placed again on his legacy through the realization of the exhibition *Hugo Häring: the world is not yet quite finished*, [Bihr, Schirren 2025] which, in addition to exploring the origins of his pretige, shows models, sketches and drawings by the architect. Despite the diversity of approaches –projectual, philosophical, social, etc.– through which Häring's legacy has been deepened, compared to other masters, there is a certain gap in the analysis of his drawings. Hence, in this article, we have considered it as an opportunity to investigate Gut Garkau project from the architect's own drawings.

Objectives

The Gut Garkau project is regarded as Hugo Häring's masterpiece and, as such, has been approached from different perspectives. The aim of this study is to reveal, through the architect's archive drawings and complementary diagrams by the authors, the different structural systems that Häring designed to construct the diverse parts of the complex, considering them as a response to the functions. The aim is to reveal this rich interaction between use and structure, one of the most powerful associations in the field of architecture.

Methodological note

The research was based on consultation of the project documentation preserved and digitalized in the archives of the *Akademie der Künste* in Berlin, which is publicly accessible through its online repository and has been previously cataloged. Unlike other case studies in which the documentation is unpublished or unprocessed, in this case the material was available in digital format, which allowed for a systematic and orderly review. This documentary *corpus*, consisting mainly of plans, sketches and writings related to the Gut Garkau project, has been supplemented by an exhaustive bibliographic review, covering both general studies on Hugo Häring's work and specific research and analysis focusing on this farm.
The methodological strategy adopted was based on the contrast between these two approaches: on the one hand, the direct examination of primary sources from the archive; on the other, the critical analysis of interpretations already present in the academic literature. This dialogue between documentary materials and theoretical frameworks has made it possible to identify convergences and discrepancies regarding the conception, development and execution of the project, as well as to detect possible interpretative gaps. The process has culminated in the preparation of a study that coherently integrates both approaches, thus providing a structured vision that serves as the basis for the analysis and conclusions presented in this work.

Theoretical foundations

In relation to expressionism, functionalism and the historical importance of Gut Garkau's project (fig. 1), Rayner Banham states that the pre-World War I works of Hans Poelzig and the non-classicist works of Peter Behrens, influenced by the English *Arts & Crafts* movement, led to an current of sculptural constructive forms that, after 1918, it was developed in Mendelsohn's early projects and reached its climax with the Gut Garkau farm of Hugo Häring (1922-1924). Unlike Nikolaus Pevsner, who in *Pioneers of Modern Design* (1936, 1960) proposed a historical alternation between expressionism and functionalism and relegated the former to the realm of "pure subjectivity", Banham recognized the existence of a productive link between the two currents. According to Pevsner, "while functionalism was supposed to be objective, scientific and anonymous, expressionism only represented personal expression" [Banham 1979, p. 30] a position that, as Banham points out, contributed, along with that of critics, such as Sigfried Giedion, to relegate the expressive-functionalist tradition as a mere romantic exercise.

In contrast, Peter Blundell Jones points out that "ironically, Scharoun and Häring were better functionalists than Gropius or Mies van der Rohe" [Blundell Jones 1999, p. 9], while Wolfgang Pehnt states that "Häring thought of form and function with more depth and logic than any other architect of the new style", [Pehnt 1999, p. 23] highlighting his realism in not assuming an automatic harmony between expression and function. This position was clearly reflected in *Wege zur Form* (1925), where Häring proposed that the expression should not be placed before or subordinate to the function, but that it should be reconciled with it, seeking a morphology "that expresses the efficient fulfillment of its function" [Häring 1925, as cited in Joedicke 1960, p. 318] and that, as in nature, "is the result of a coordination of many parts" [Häring 1951 as cited in Joedicke 1960, p. 318] for the benefit of the whole. It was Häring himself who distinguished two stages in the design process: *Organwerk*, which consists of helping objects to find their correct shape based on changing requirements, and *Gestaltwerk*, in which they find an adequate architectural expression. It recognizes the value of vernacular forms originated by functional needs and combines traditional techniques and materials with contemporary resources, which, it gives it a much wider expressive variety. His organic vision, influenced by William Morris, William Lethaby and by his teacher Theodor Fischer, assumes that specific geographical and cultural conditions can shape architectural form, so that the building "grows organically from the inside out" [Fischer 1927, as quoted in Nerdinger, Gottardo 1990, p. 17] and respects, as Wright would say, "what grows from the nature of things" [Wright 1954, p.18].

The Gut Garkau farm

The architectural complex

Häring designed the Gut Garkau agricultural complex (Klinberg, Schleswig-Holstein, 1922-1925) materializing the theories proposed that same year in his essay *Wege zur Form* [Pizza 2002, pp. 199-201] [1], which was illustrated with drawings of the farm under the title *Funktionelles Bauen: Gut Garkau, das Viehhaus* (Functional building: Gut Garkau). Häring arranged the building pieces carefully integrated with the vegetation on the west shore of the small Pönitzer See Lake. He took advantage of the irregular and sinuous perimeter of the plot to naturally place the many elements that define the farm

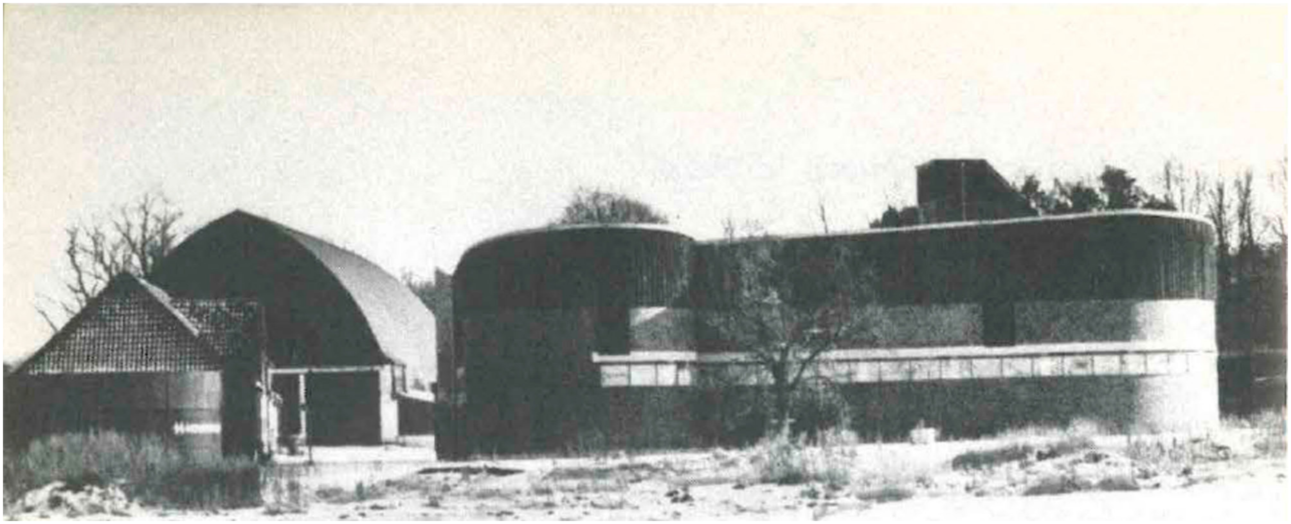


Fig. 1. Photograph from the north, on the left the barn and on the right the stable [Bucciarelli 1980, p. 44].

(a stable for cows, another for horses and pigs, a barn, a chicken coop, the farmer's offices and main home, as well as several buildings for machinery). Häring abandoned the traditional system of aligning spaces around a central axis in favor of a formal principle that simplifies the necessary manipulations and the distribution of movements of animals and workers to manifest themselves in an organic space [Behrendt 1924, pp. 347-352]. Between 1923 and 1924 Häring made three proposals for Gut Garkau's set, as coherent variations of the same idea. From the third proposal, the one finally built, we have the drawings of 1924: the axonometry, the elevations-sections and the general plan preserved and classified in the Baunkunstarchiv archive of the Akademie der Künste in Berlin.
As can be seen in the site plan (fig. 2), the various agricultural buildings are enclosed around a trapezoidal corral with its own access, located to the north of the plot, and are separated from the main house and offices, at the southern end of the farm, by a more representative courtyard with its own access and views of the lake. In the delicate axonometry drawn by Häring (fig. 3), we can see how the clear contours delimiting the different parts that appeared in the general plan are transformed into a complex organism made up of multiple volumes that are closely related to each other. The variety of forms and scales of the different parts express Häring's concern not only for the interrelationships between the buildings, but also with the outdoor spaces they form. The buildings facing the interior of the courtyard do not reveal their full height; Häring proposes a more domestic scale for the interior, adjusted to the human dimension. The connections between the buildings via working porches, linking the different entrances and exits for the animals, as well as the careful layout of the vehicle entrances for loading

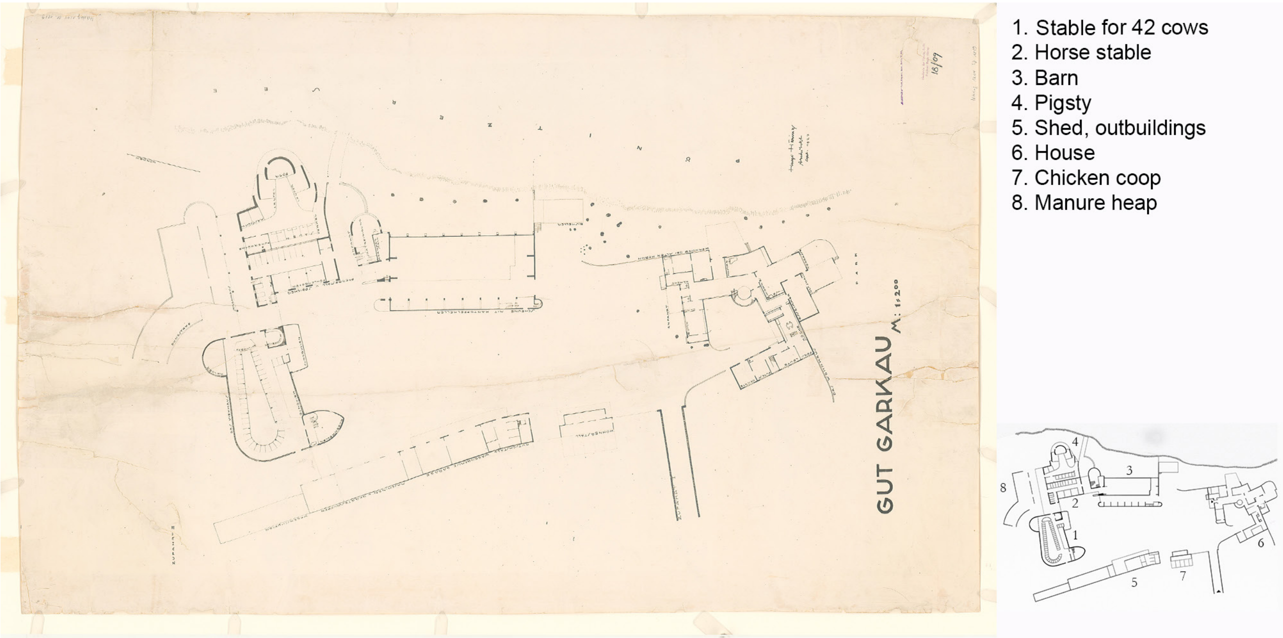


Fig. 2. Location Plan, Häring-Hugo_1204_018_009-1024w, Akademie der Künste, Baunkunstarchiv, Berlin.

and unloading both livestock and grain, demonstrate the extensive functional and organizational study behind the architectural proposal [2].
But beyond mere functionalism, Garkau transcends the schematic through a deep understanding of the program, the place and nature, thus finding the most appropriate architectural form [Abascal García 2010, p. 74]. "We do not seek to feed the apparent antithesis between expressive and functional […] we try to affirm expressive needs in the direction of life, of becoming, of movement, through a natural configuration, because the itinerary that shapes the functional form is consistent with the natural one. In nature, form is the result of the arrangement of multiple data in space, in relation to the evolution of life and both individual and complex efficiency" [Pizza 2002, p. 200]. On the other hand, Häring found structural humility and functional sincerity in vernacular forms. This recognition, adapted to new human needs, implied a reconsideration of the techniques and materials with which they were built. Häring's projects show a combination of vernacular construction resources associated with other contemporary ones. "This seemingly […] mixture gives him a wide range of expression, impossible to achieve with more abstract and limited vocabularies [Blundell Jones 1999, p. 70].
Although Häring developed new proposals for the horse stable and pigsty (1926), which would have closed off the corner joint, strengthening the architectural integrity of the complex, only the cattle stable and the barn (1925) were completed.

The barn

The barn building was placed in the north-western part, closest to the lake. It acts as a closing element of the complex towards the lake but respects the trees on the riverbank by separating itself by about 20 m. Häring will slightly hide the large volume among the trees to minimize the visual impact despite being the largest piece in the complex. The building consists of a rectangular central section measuring 15.50 m by 36.14 m with a pointed arch roof supported by a *Zollinger* type wooden structural system (fig. 5) and a smaller section attached to the courtyard measuring 2.97 m by 35.85 m.
There are three plans for Hugo Häring's 1924 barn construction project, deposited and cataloged at the *Akademie der Künste* in Berlin. The first of these (fig. 7), due to the overlapping lines and details, can be assumed to be the development plan for the work. The drawings, which faithfully and concisely reflect the constructed project, do not show the connecting element with the stables and pigsty, as proposed in the general plans. The floor plan combines the ground floor and basement in a single line drawing. The elevations and sections show corrections and annotations of the heights of the wooden slats of the gable framework.
The second plan (fig. 8) appears clean in its presentation. The plan and section view showed the construction of the connecting element with stables and pigsty and raised the hypothetical possibility of its construction. The basic dimensions of the building are established in both the section and the plan.
The last of the plans (fig. 9) shows larger-scale details of the southern volume of the side bay, defining the

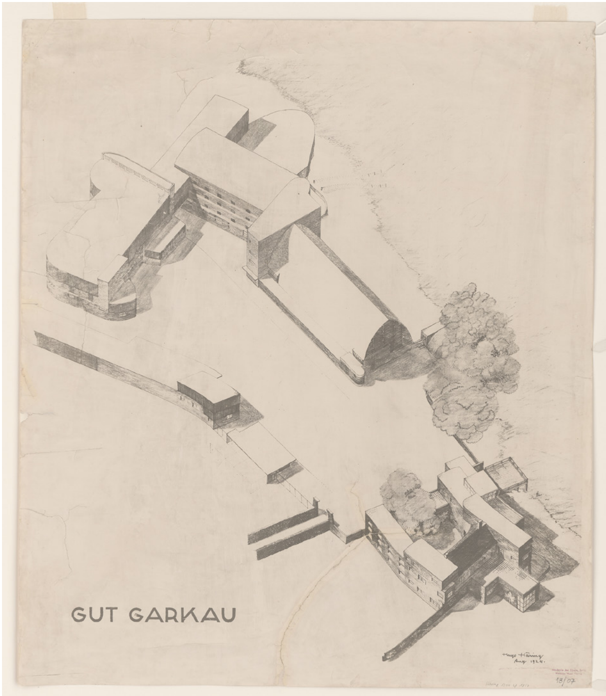


Fig. 3. Axonometry, Häring-Hugo_1204_018_007-1024w, Akademie der Künste, Baunkunstarchiv, Berlin.

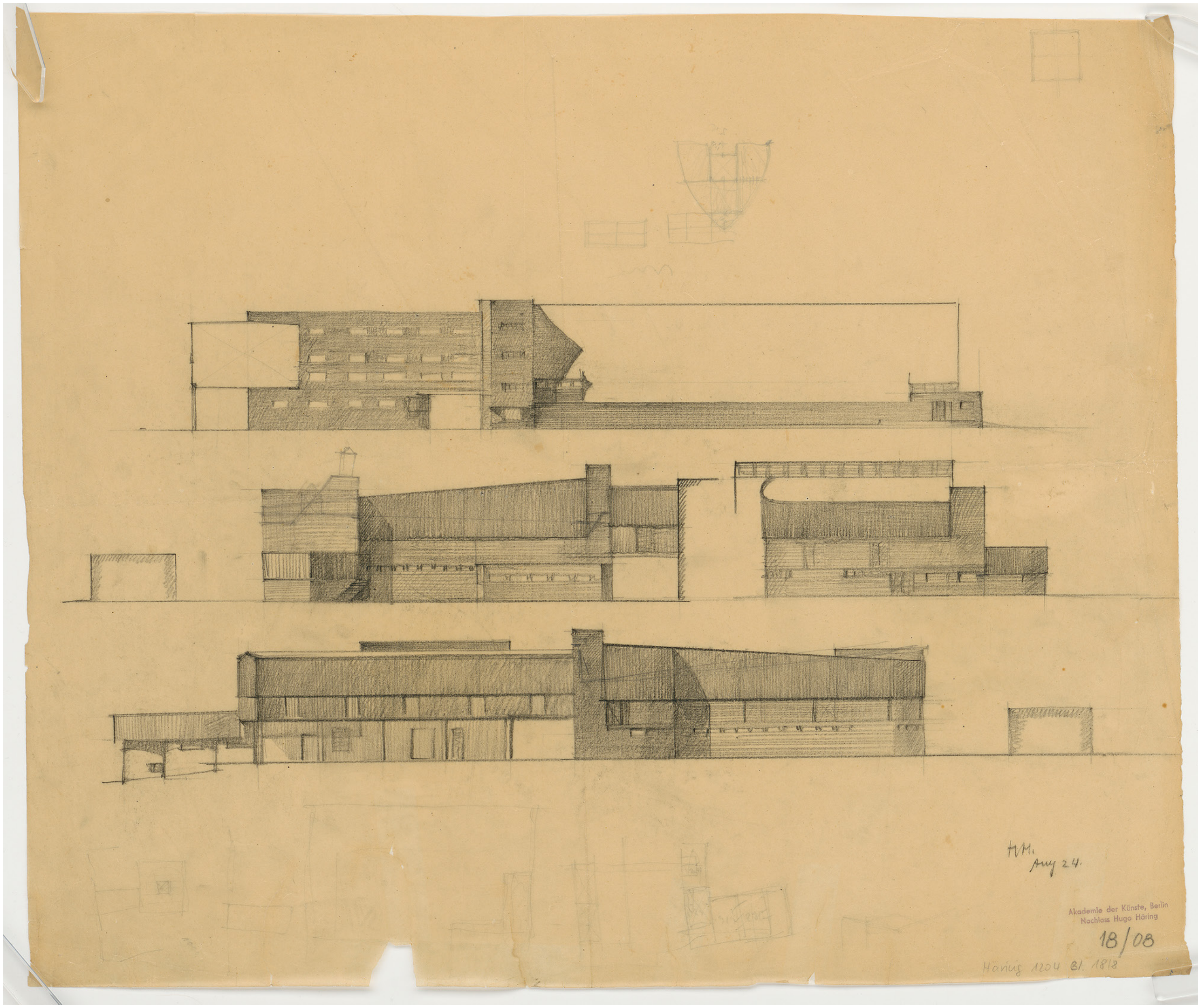


Fig. 4. Elevation – sections, 1. Residence and barn, 2. Stable and Pigsty 3. Stable and horse stable, Häring-Hugo_1204_018_008-1024w, Akademie der Künste, Baunkunstarchiv, Berlin.

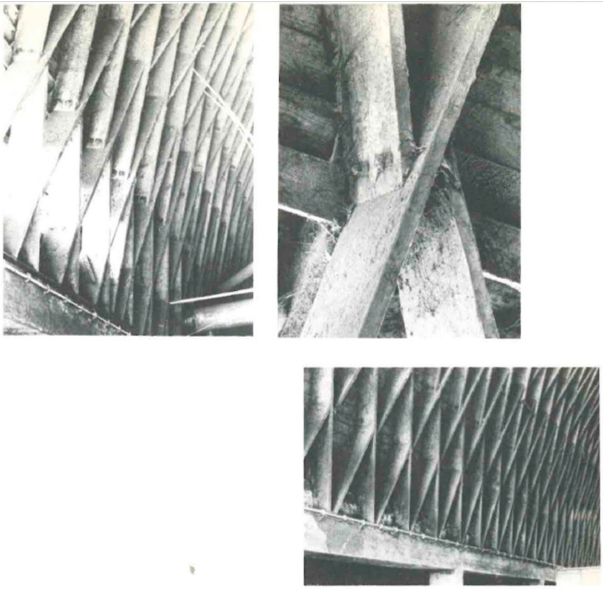


Fig. 5. Photo of the barn under construction Akademie der Künste, Hugo-Häring-Archiv, N°54, Berlin.

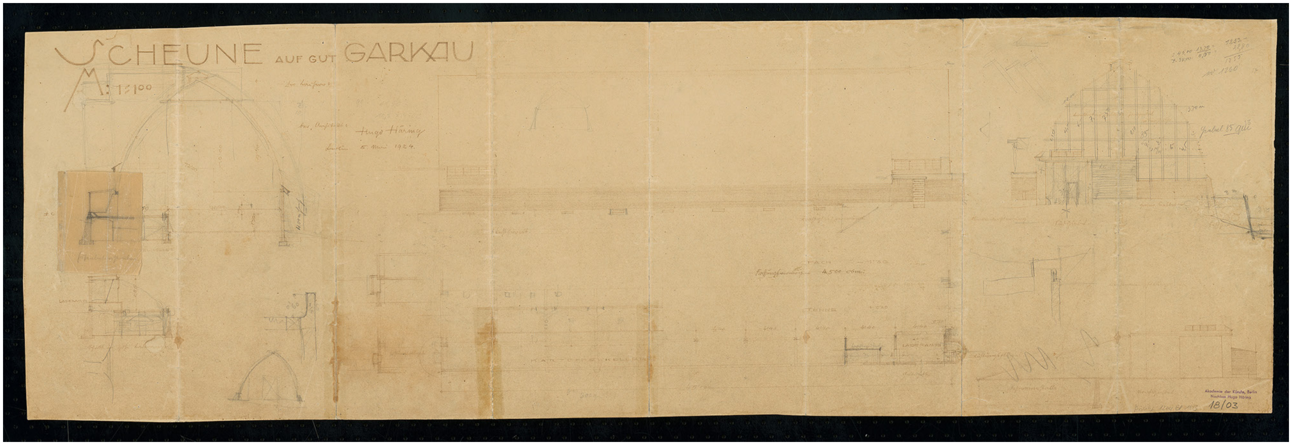
Fig. 6. Barn interior details [Bucciarelli 1980, p. 53].

exterior façade and the brickwork of the loading bay and the staircase leading to the basement. All these documents reflect the direct importance between thought, drawing and construction. The barn's design seeks to achieve maximum height using the thinnest possible structural thickness while recalling the curved profile of farms in northern Germany. To achieve this, Häring uses a construction made of thin sheets of wood nailed together to form a light three-dimensional mesh of rhombuses, a technique based on a system known as a *Zollinger* roof. The spatial structure is separated from the ground by resting along an exposed concrete wall on the side facing the lake, while on the opposite side it rests on a sturdy portico, also made of reinforced concrete, which supports a series of auxiliary buildings. On top of this perimeter plinth, a grid of wooden studs and straps is constructed on the gables to serve as a base and reinforcement for the exterior finish, which is made of large horizontal panels of treated planks.

Following the tradition established by Poelzig, Häring draws on the nature of materials and the way they are used to achieve expressive rhetoric in the building while establishing a dialogue with the surrounding landscape. Thus, the barn combines traditional materials, such as black Flemish tile roofing and red vitrified brick (laid in an English garden bond pattern, as in the old farms of Schleswig Holstein), with techniques that were more innovative for the time, such as reinforced concrete lintels and walls.

Häring even allows himself to experiment with variations on the most common details: in the vertical bond used in the circular corner that crowns the annex, in the highlighted bands that enliven the basement of the main façade of the barn, and in the composition of the large sliding entrance door, which uses three types of wood cladding.

These expressive resources introduce an ornamental extension to the nature of the construction, beyond pure functionality, which, in Häring's own words, "[…] may seem like a betrayal of functionality in favour of the purely ornamental", where "[…] if ornament is the correct word, it is a very special form of ornament. Because even if it produces a visual effect, it is realised within the discipline of the construction process, in fact, as a deliberate elaboration of it: construction elevated to the level of a game. This duality has strong precedents in the German vernacular tradition" [Blundell Jones 1999, p. 58].



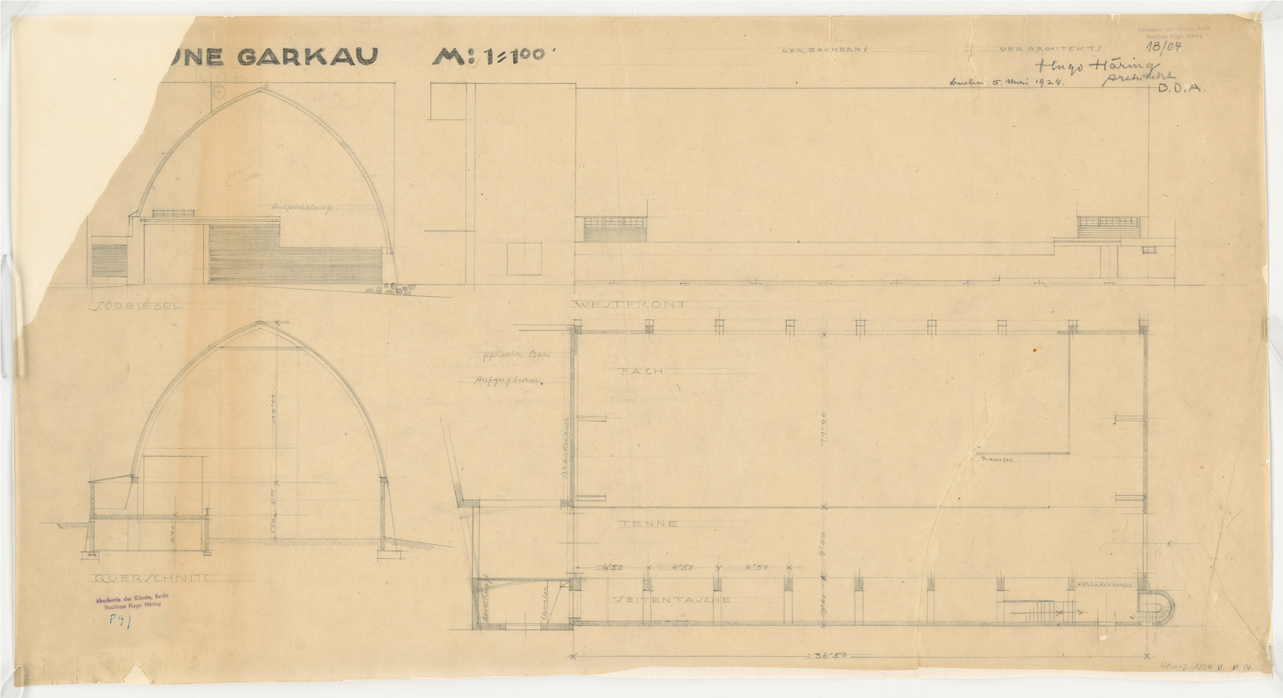


Fig. 7. Ground floor, elevations and section, Häring-Hugo_1204_018_003-1024w, Akademie der Künste, Baunkunstarchiv, Berlín.

Fig. 8. Ground floor, elevations and section, Häring-Hugo_1204_018_004-1024w, Akademie der Künste, Baunkunstarchiv, Berlín.

The stable

The stable is the most notable piece of Gut Garkau's ensemble, it is the irrefutable embodiment of the beginning of theoretical thought in the beginnings of Hugo Häring around 1924. The building is arranged at the north-western end of the *hof* –or courtyard– and closes the interior space in this direction acting as a backdrop. Only a plan of the floor plan is preserved of the stable project of Gut Garkau, (fig. 9) –undated, drawn in pencil, plan that includes the final version and corresponds to the rest of the general documentation of the complex analyzed above, also from 1924.

However, the only documentation available that corresponds to the final plan (fig. 10) bears no relation to the volume of the final proposal in the axonometric projection and elevations/sections of the general layout analyzed previously. The stable has a single-slope roof in the opposite direction to the final design, a skylight/ventilation on the north side that was never built, and the hopper has a different configuration. In addition, two detailed plans have been preserved, one partial plan of the north elevation and another with details and fittings of the brickwork.

The complexity of the stable is enormous, and the geometric construction initially seemed impossible. However, thanks to the precision of the architect's drawings, the rigor of the measurements and the consistency of the process, it was possible to bring it to fruition. With an approach close to that stated by Mendelsohn, who seeks form in the expressiveness of the structure, Häring's proposals attempt to achieve a morphology of the supporting structure that expresses the efficient fulfillment of its function [Joedicke 1960, p. 318] [3]. "In nature, the image is the result of the coordination of many parts, in such a way that allows the whole, as well as each of the parts, to coexist in the most effective manner […] if we try to discover the true 'organic form', instead of imposing a foreign form, we will be acting in accordance with nature" [Joedicke 1960, p. 318] [4].

"For the stable of 42 cows, a pear-shaped plant was determined as the most suitable. The fodder went down from the hayloft to the feeders, which at the same time functioned as a threshing floor. This arrangement makes the feeding process much easier. At the same time, the manure is cleaned using a one-way system"

Fig. 9. Author Collage, Brick Rigging Details, Häring-Hugo_1204_018_005-1024w, Akademie der Künste, Baunkunstarchiv, Berlin, and source Impegno nella ricerca orgánica [Bucciarelli 1980, p. 52].

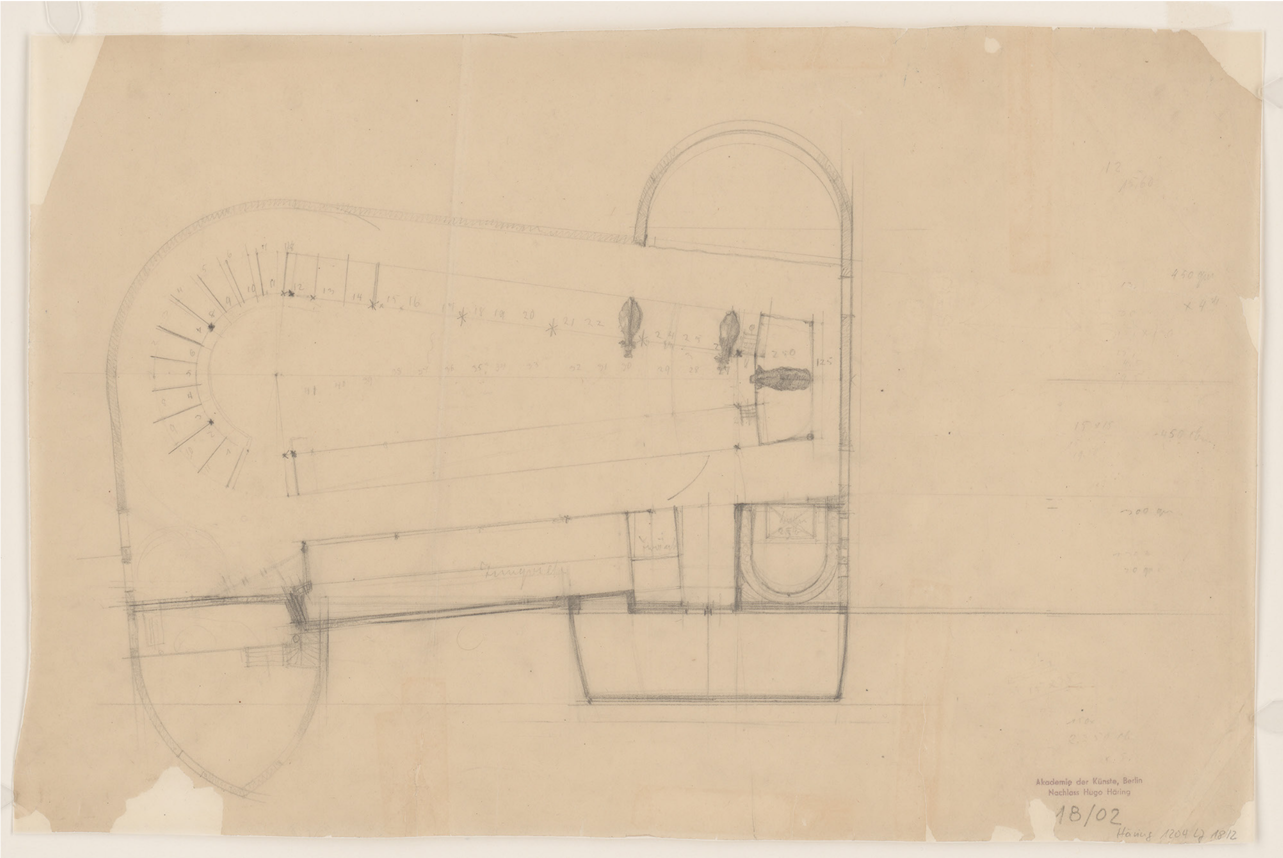
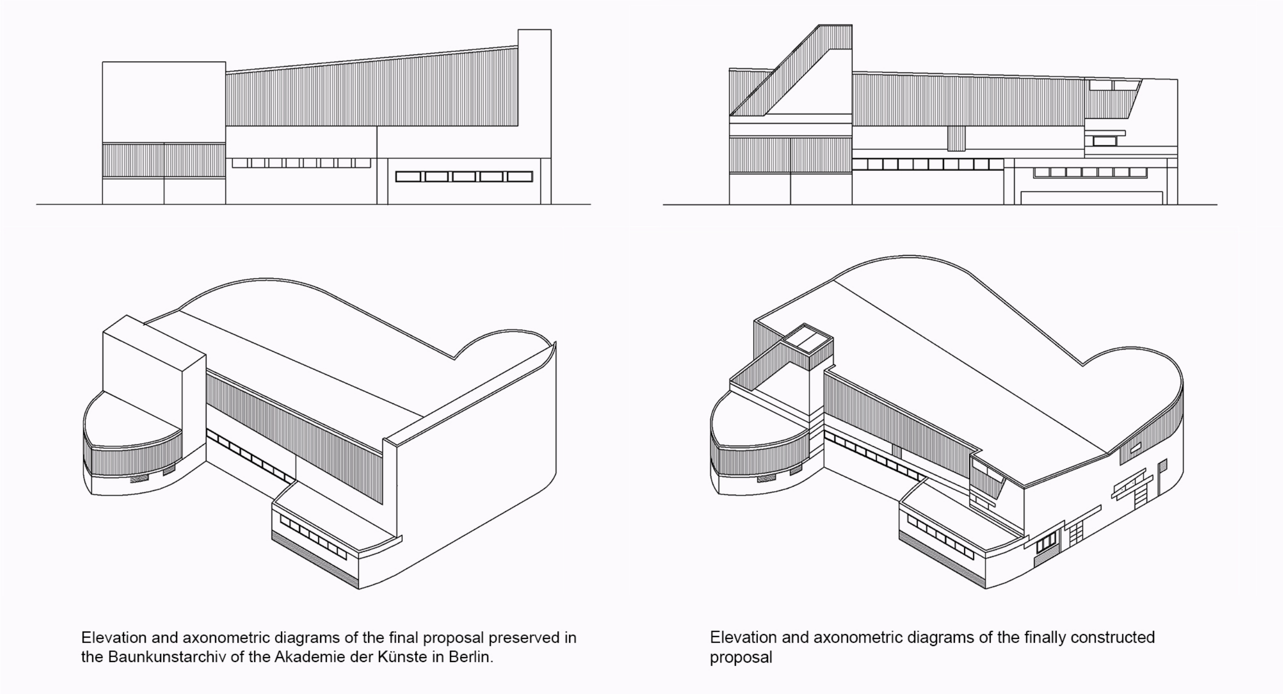


Fig. 10. Stable Plant – undated, Häring-Hugo_1204_018_002-1024w, Akademie der Künste, Baunkunstarchiv, Berlín.

Fig. 11. Elevation and axonometry diagrams of the stable (graphic elaboration by the authors).

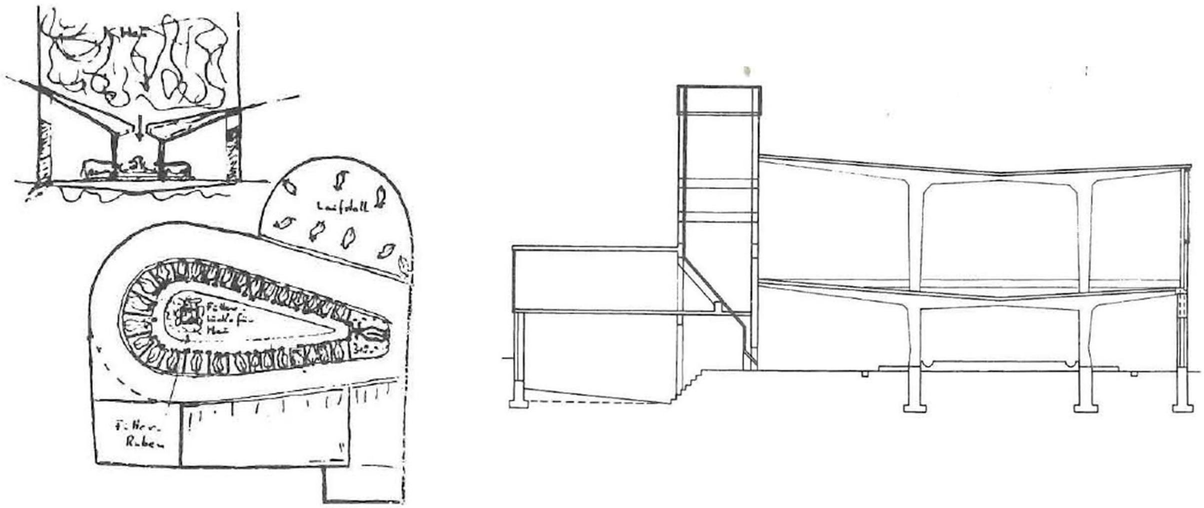


[Häring 1925, pp. 16-17]. Animals are not placed facing each other, so they do not directly share the exhaled air, reducing the risk of diseases. Livestock control is facilitated from behind with a curved perimeter corridor and at the head from the feeding space.
Like traditional agricultural buildings, the stable has two floors, the ground floor for cattle and the upper floor for straw. The section is organized in a "V" with a slope of 1:8 inwards to promote ventilation. A first slab 20 cm thick separates the stable from the hayloft (fig. 11). The perimeter level is constant horizontal and has a longitudinal slope also in a "V" shape with a low point in the western third to pour the straw over the center of the stable, slopes that allow the feed to be dragged to the point of pouring to the bottom. That "V" slope in the upper hayloft slab is repeated on the slope on the deck to collect the waters. With this section gesture in the form of butterfly wings in the stable, you also solve the collection of water inside, ventilation and leave a clean profile on the outside.
The geometric conditions of the building are difficult to understand, but the outline is harmonious. The space for calves, young calves and dairy cows is attached to the main volume as a kind of "backpack" determining the shape of the building. In this initial sketch of Häring, it can be seen that there is a space planned for the haystack, the spaces for horses and storage would come later. The form of construction arises when it is sought to be the natural result of achieving the functionality of the work in the simplest and most direct way. "Naturally, there is no room here for influences of any other kind, such as folk art, traditions or crowned pediments, and yet the construction sits on the territory and landscape with much greater roots than the older buildings in the area" [Häring 2002, pp. 67-75].

The structure is built with concrete porticoes (fig. 12), sheets with a double central support and large overhangs, which are not really such because the ends are supported on the supports that, being hidden inside the double layer of brick and glass, seem to disappear. The windows are located in the upper part of the wall just below the slab line and are not practicable so that the ventilation of the enclosure does not depend on their opening. Light enters through this perforated perimeter ventilation hole from above, generating a suspension effect of the upper slab.
The angle of the section is present in the plan, the flat gantries are flexed in the center to be placed perpendicular to the perimeter and the central beam section between supports is strengthened. In order not to show the curve from below in the slab of the ceiling of the ground floor, the beams that in this case protrude on the floor of the hayloft partially disappear. The structure is arranged on the edge of the trough tray, so that its creative foundation comes from the functional, and consists of 6 large concrete pillars that dismiss a system of beams inwards and outwards.
"Through the materials of construction, the work of the spirit begins to become visible in earthly reality, in which materials, as bodies, occupy a space" [Häring 1951, as cited in Joedicke 1960, p. 318]. Häring makes a reading of the traditional construction model, in which the lower part is solid to protect animals from the weather and predators, and help to overcome changes in elevation. The upper part is made of wood to open holes easily in such a way that ventilation and hay storage are allowed. The exterior walls of the stable are not load-bearing, this kind of plinth only acts as thermal and climatic insulation, half is made of annealed brick and the other of concrete.

Conclusions

The present study has made it possible to evidence, from the few graphic documents preserved and the elaboration of interpretative schemes, the clarity with which Hugo Häring articulates the relationship between structure, function and formal expression on the farm of Gut Garkau (1923-1924). The study confirms that the structure cannot be understood only as a technical resource aimed at guaranteeing stability, but as a design principle with the capacity to generate form. In this way, the structure reveals itself not only as a support, but as a design engine, simultaneously articulating function, spatial coherence and aesthetic expression. The analysis reveals a double construction-structural strategy: concrete in the stable, designed to respond to the demands of this type of space, and *Zollinger* type wood in the barn, which provides lightness and spatial adaptability. This duality does not respond only to technical criteria, but embodies Häring's idea that "each function must find its own form" [5], integrating structural logic and architectural expressiveness. In this way, it is confirmed that formal expressiveness does not arise as an aesthetic addition, but as a direct consequence of the adequacy between structural, constructive and functional means. In this sense, Häring's projects anticipate an organic conception of architecture, in which drawing, function and structure are inseparable dimensions of the same design process.
The line of structuralist expressionism with vernacular overtones initiated by Poelzig and developed in the post-war years by Taut, Mendelsohn and Häring, was "inhibited by Dutch and Russian abstract aesthetics, and would soon be reduced to nothing" [Banham 1985, p. 88], but would revive in the architecture of the fifties, and as Reyner Banham indicates, Gut Garkau's advanced work could be considered to be present in Alvar Aalto's fully mature works [Banham 1979, p. 30]: "With the arrival of Aalto, a second stage in modern architecture began; it was then that Häring's ideas took on a new breath of life, although he was unknown to most of the men who used them" [Joedicke 1960, p. 318] [6]. Although this way of thinking about architecture, intertwining function, structure and materiality, in an attentive way to the vernacular tradition, did not have much more projection immediately, it would flourish strongly in later decades. It would generate again, at the end of the fifties, a great interest among many of the English architects linked to Brutalism. Young people interested in the revaluation of construction and materiality as indispensable companions of the function. Despite the lack of specific references that show that the two main theoreticians of Brutalism, Alice and Peter Smithson, had knowledge of Häring's texts, the Garkau farm is mentioned in the previous notes of the manuscript *New Brutalism* (1955). Häring, along with Aalto, Duiker and Rietveld, will be vindicated as a key figure in 'the other tradition' in the book on the origins of the *Modern Movement, The Heroic Period of Modern Architecture*, which the Smithsons published in 1965.



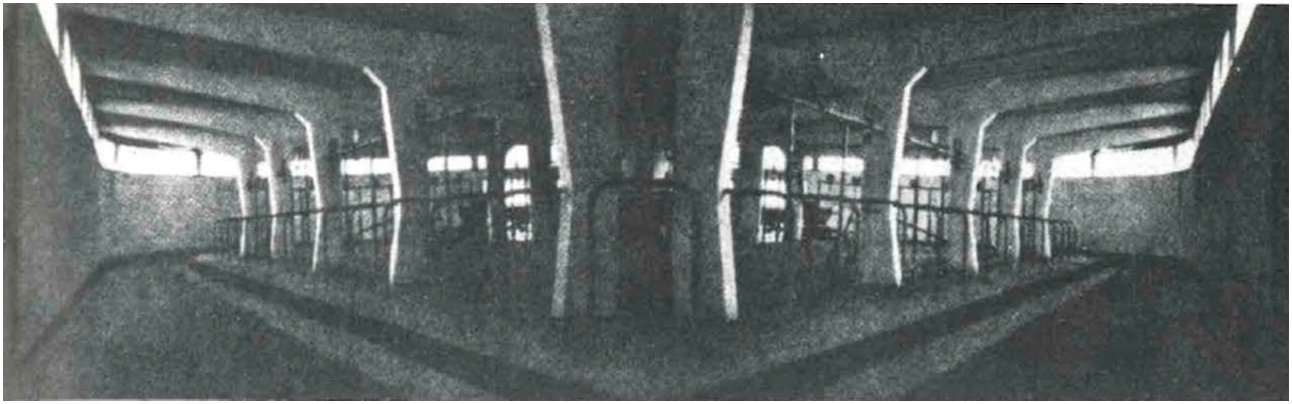


Fig. 12. Häring's preliminary sketch of the stable [Schirren 2001 , p. 362] y Stable cross-section [Bucciarelli 1980, p. 47].

Fig. 13. Photomontage of The Lissitsky (1927), stable interior of Gut Garkau [Bucciarelli 1980, p. 51].

Notes

[1] See also: García Roig 2006.

[2] The Gut Garkau farm, commissioned by Otto Birtner, attracted numerous farmers in its early years, who were interested in the new livestock and machinery facilities, thanks to the application of experimental agricultural criteria and the innovative architecture of Häring.

[3] Häring, H. (1925). Form findung nicht Zwangsform. In *Die Form*, Vol 1, pp. 3-5. Cited in: Joedicke 1960.

[4] Häring, H. (1951). Geometrie und Organik. In *Baukunst und Werkform*, pp. 132-136. Cited in: Joedicke 1960.

[5] In 1928 he published a text entitled *Architektur als Organismus* (Architecture as Organism), in which he argued that architectural form should arise from specific function and conditions, not from standardized models or imposed style.

[6] Joedicke, J. (1960). Haering at Garkau, *Op.Cit.*, p. 318. See also Bucciarelli 1980.

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Geometrical Analysis of Vilanova Artigas's Trapezoidal Columns

Wilson Florio, Ana Tagliari

Abstract

Constructive honesty was one of the premises of modern architecture. The best way for architects to make reality perceptible was to leave the structural elements apparent. From 1930 to the 1960s, this discussion took place in Brazil. In this way, one question emerged: What is the symbolism of a structural column in modern architecture? In the present article, we discuss the geometry of columns designed by the architect João Batista Vilanova Artigas (1915-1985) between the '50s and '60s. Vilanova Artigas documented his vision of architecture in his texts, which discuss the relationship between architecture, technique, and construction. We identified concepts that guided his design strategies, particularly how structure shapes architecture. Our research used drawing as a powerful tool to reveal geometrical characteristics in the constructed buildings, as well as to contribute to clarifying these concepts. Based on the original technical drawings, we modeled the structure of selected projects to investigate and reveal the constructive system, paying attention to the geometrical characteristics of the columns. The obtained results allowed us to demonstrate the sculptural character of the Vilanova Artigas columns based on the morphological analysis of the trapezoidal geometries. Furthermore, the research results reveal that Vilanova Artigas designed his architectural projects and structural conception as one thing, in an original and innovative way, harmonizing art and technique.

Keywords: construction process, form-generating, symbolism, reinforced concrete, aesthetic emotion.

Introduction

The column has always been an important element in architecture. Since the Greeks and Romans, the classical orders have played a fundamental role in the construction of the language of a building.
In the modern scenario of the 20th century, Le Corbusier (1887-1965) reinvented the design of the column for the pilotis, devoid of ornaments and with functional protagonism. On the other hand, Frank Lloyd Wright (1867-1959) advocated the structure integrated into the building as a single organism. In Brazil, between the '50s and '60s, Oscar Niemeyer (1907-2012) offered us several creative designs of the modern column, especially in the palaces of the city of Brasília, highlighting the curve and delicacy provided by the strength of reinforced concrete. But the geometry and design of the modern column were explored and enriched by the architect João Batista Vilanova Artigas (1915-1985). This paper presents the results of research that analyzed architectural projects designed by the Brazilian architect Vilanova Artigas. One of the stages of the methodology of this exploratory research was developed in the archives of architectural projects in the Faculdade de Arquitetura e Urbanismo e de Design Universidade de São Paulo (FAUUSSP) library. In these archives, we found important drawings of the projects selected for analysis. In this text, we present the drawings of the architect's projects, which reveal the structural conception. The subject matter is

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previously unpublished material by this important architect of the well-known São Paulo School.
Vilanova Artigas documented in his texts his vision of architecture, which clearly shows his posture as an architect in the relationship between architecture, technique, and construction. In this research, we identified fundamental concepts that guided his design strategies. Experiments with new spatial propositions and technical solutions produced an innovative character, especially in terms of structure as defining architecture, the nationalist spirit, and the valorization of human and collective spaces.
The procedures adopted in this research consisted of a literature review on the subject, a survey of projects and drawings, visits to selected buildings, and analysis of projects through diagrams, drawings, models, and writing texts. The research results reveal that Vilanova Artigas designed his architectural projects and structural conception as one thing, in an original and innovative way, based on his concepts of modern architecture for São Paulo. The architectural project and structural conception together organize the architectural program and contribute to the materialization of modern concepts of its architecture.
The investigation employed theoretical writings, case studies, and graphical analysis to analyze the geometric development of trapezoidal columns in Vilanova Artigas architecture. The main steps were: I) identify the main concepts declared and written by the architect; II) select projects with columns with different geometries; III) 2D redraw and 3D modeling of each column; IV) 3D printing of the modeled columns; V) identify geometrical characteristics; VI) classify types of columns in categories; VII) discuss the results and analyses. The article is organized into four parts: *Introduction*; *Column in modern architecture*; *Research*; *Discussion*.

Column in modern architecture

Physically, a column serves as a point of support and a structural element that ensures the structure minimally impacts the terrain. Structurally, columns are used to transfer the compressive load of a building to its foundations.
Columns are frequently used to support beams on which ceilings rest. But a portico is an assembly where a column is part of a broader structural configuration with beams, trusses, and roof coverings. Therefore, a portico is a structural frame with multiple load-bearing members and a roof, functioning as an integrated system. Historically, ribbed reinforced concrete slabs with trapezoidal beams emerged with Hennebique's patent in 1892. There is no doubt that the structure of Notre-Dame du Raincy, by Auguste Perret, built in 1922, had a significant impact and inaugurated the so-called 'Brutalist architecture' [Collins 2004; Frampton 1996]. The 37 feet tapered columns clearly show the presence of an unfaced concrete support that "imprints half-round and triangular timber fillets from which the column formwork is constructed" [Frampton 1996, pp. 131, 132]. However, it was Le Corbusier, through the concept of *beton brut*, who comprehensively articulated the notion of allowing concrete to reveal its inherent aesthetic by remaining unadorned and untreated.
In modern architecture, Perret made round columns. According to Peter Collins, this shape was preferred because it was most economical, providing constant rigidity from every angle, and because "it was more satisfactory optically as a result of the gradations of shadow and constancy of silhouette" [Collins 2004, pp. 202-203].
As Joseph Rykwert [1996] observed, for ages columns were made of stone as vertical supports. With the advent of reinforced concrete as a malleable material and the ability to calculate the forces within it, architects began the exploration of several different shapes, resulting in the development of columns with a variety of forms, including *V*, *Y*, and *W* shapes, as well as porticos with intriguing angles of inclination, which challenged the canons of architecture in the 20th century.
Modern architects, such as Le Corbusier (1887-1965) and Frank Lloyd Wright (1867-1959), created new ways of conceiving the structure of their buildings, exploring construction techniques in an innovative manner. Le Corbusier advocated for using pilotis as support to elevate buildings above the ground, which are typically organized in a systematic grid, while Wright explored more organic forms that utilize dendriform and trapezoidal columns.
From 1930 to the '60s, modern architecture intensified this discussion in Brazil to promote a national identity. Starting in the '40s, Niemeyer created a set of columns in Brazil that challenged traditional construction techniques, first with the buildings designed for Pampulha in Minas Gerais and later with the architectural ensemble for Ibirapuera Park in São Paulo. Together with Afonso Reidy (1909-1964), they created innovative structures in Rio de Janeiro. As a result of these events, in the '50s, after the great international acclaim of Niemeyer's work, architects like Vilanova Artigas were inspired to create structures

with expressive forms, in search of architecture that had a Brazilian national identity.
In 1956, Henrique E. Mindlin, in his book titled *Modern Architecture in Brazil,* emphasized that the pilotis were "practicable in Brazil because of the climate, the freeing of the ground vindicates all the claims Le Corbusier has made for it and results in a better integration of interior and exterior space" [Mindlin1956, p. 12].
From the increasing appreciation of the architectural expression of structure that occurred after World War II, engineers like Pier Luigi Nervi (1891-1979) began a profound investigation into new ways of conceiving structures for ever larger spans, with columns and porticos left exposed, without cladding or extensive finishes, within what was termed the new Brutalism. As a result, the constructive truth that emerges from the exposed structure serves as a motif for aesthetic expression.
In partnership with engineers knowledgeable about reinforced concrete techniques, architects like Marcel Breuer (1902-1981) explored, especially from the '50s onward, innovative structures. As Robert McCarter aptly defined, "the UNESCO project was a true collaboration for Nervi and Breuer, and Breuer later said that it was Nervi's vision of geometry, his ability to develop an organic system of structure, and his very human genius that made their association meaningful for him" [McCarter 2016, p. 156]. This fruitful partnership also facilitated the development of columns and porticos far beyond what had been achieved up to that point.
As Pier Luigi Nervi rightly wrote, "it would be impossible to create Poetry (Architecture) just as it is to write correct prose (Good Construction) without perfect knowledge of words and the rules of grammar and syntax (Technique)" [Nervi 1963, p. 9]. In this way, art and architecture guided by poetry and technique conducted to honestly reveal the constructive system.
During the 20th century, a growing number of concrete columns and porticos were conceived as sculptural, expressive, and meaningful in their role of suspending buildings off the ground. From the understanding that a beam needs a column, as well as a column needs a beam [Kahn 1969], as Louis Kahn declared in the text *Silence and Light*, in 1969, the columns were lapidated as a diamond.
In fact, as Robert McCarter wrote, "the emergence of visible structure, and its 'sincere expression' in Breuer's work, was paralleled and made possible by his engagement, beginning in the '50s of reinforced cast-in-place structural and finish concrete as his building material of choice. In this way, as Breuer said: 'The structure itself became art'" [McCarter 2016, p. 259]. In the '50s, reinforced concrete was explored in different ways, contributing to achieving a more expressive language.
In his career as an engineer and architect, and after his extensive experience in the design and construction of buildings, Vilanova Artigas declared: "structures have multiplied and differentiated. They enable new volumes, stealing the expressiveness of the old forms. They are the ones that define the building" [Vilanova Artigas 2004, p. 140]. Thus, Vilanova Artigas explored the structure as a fudamental part of his understanding that the poetic construction of space should challenge canons and precepts, providing identity to his architecture.
In Vilanova Artigas's architecture, the creative truth derived from the unveiled structure served as a motif for aesthetic expression itself. As the architect himself correctly stated regarding Perret's phrase: *"l'architecture, c'est l'art de faire chanter le point d'appui"* [Vilanova Artigas 2004, p. 224].
During the '50s, modern architects on different continents explored a lexicon of trapezoidal columns. In Brazil, Niemeyer's *V*, *Y*, and *W* columns in his design for the Lagoa Hospital in Rio de Janeiro in 1951, those designed in Ibirapuera Park for the *Palace of the States*, *Palace of the Nations*, and the *Palace of Agriculture* between 1952 and 1953, and the columns of the *Alvorada Palace* in 1956 are the ones that most inspired Vilanova Artigas in his projects featuring trapezoidal columns. Niemeyer declared that "moving the columns away from the facades" [Niemeyer 1998, p. 27] allowed creating a beautiful effect, and sometimes making a "wall of translucent glass blocks undulates past the circular columns" [Styliane 2008, p. 130]. Furthermore, Vilanova Artigas's work was also influenced by the columns of the Museum of Modern Art in Rio de Janeiro, designed by Afonso Reidy in 1953.
But it is also important to highlight that Vilanova Artigas had visited *Florida Southern College* in 1946-1947, designed by Frank Lloyd Wright between 1938 and 1954, where he could prominently notice the organic, trapezoidal columns of the American architect. The columns of the *Johnson Wax Administration Building* (1936-1939) certainly had a great impact at the time when photos of its construction and the completed work were published.
The trapezoidal columns located inside St. John's Abbey, as well as the tree structures of St. John's University (1953-1968), inspired modern architects.

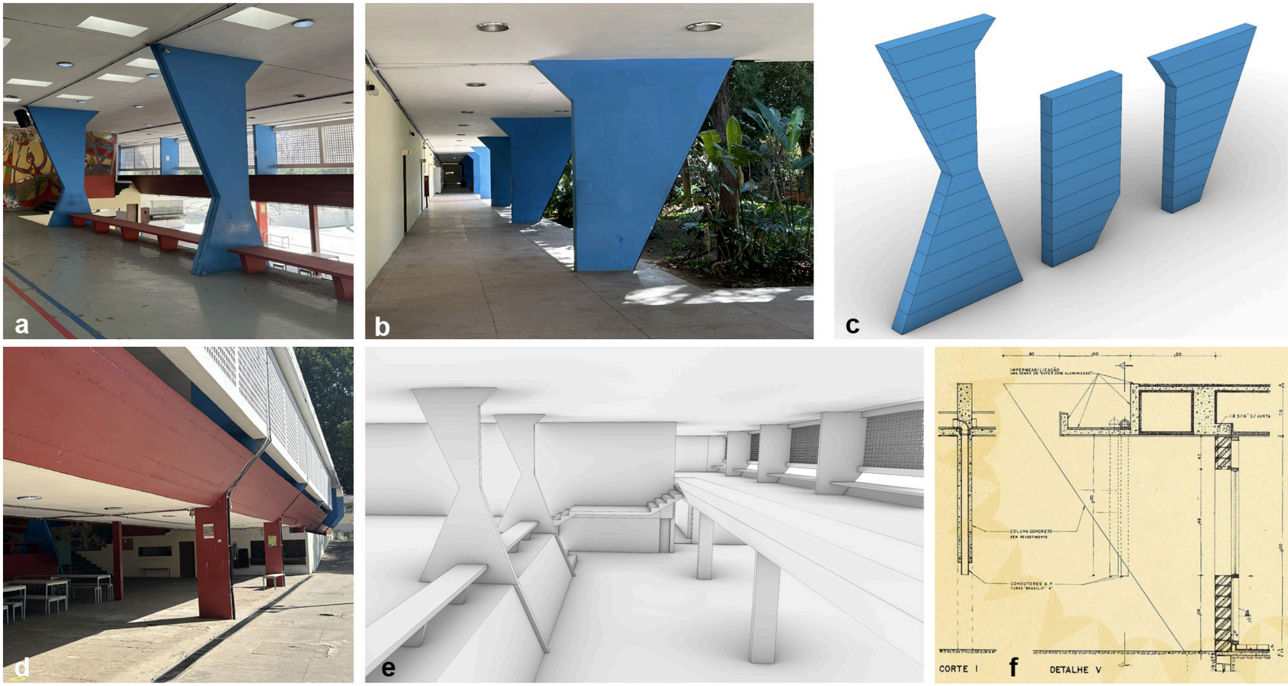

Fig. 1. a., b., d.: Photos of Guarulhos Gymnasium (photos by the authors); c. three types of columns (model by the authors); e. 3D rendering of the interior of the building (elaboration by the authors); f. constructive drawing (surce: Acrópole 1961, no. 274).

In the '50s and '60s, robust columns made new ways to generate space possible. As Louis Kahn well declared, "a column should still be regarded as a great event in the making of a plan" [Kahn 1957, p. 2]. On the other hand, "in architectural literature, columns and capitals are classified as details, but so are *piani nobili*, porches, and pergolas" [Frascati 1984, p. 501], a democratic space.
It is important to note that Vilanova Artigas was probably aware of what was happening in European countries during this period, such as the robust *V* columns of the *Unité d'Habitation of Marseille* by Le Corbusier (1946-1952); the porticos designed by engineer Nervi, particularly for the Pirelli Building in Milan (1955-1956) and the *Palazzetto dello Sport* in Rome (1957); or the columns designed by Marcel Breuer in the UNESCO 4th Building (1955-1958), in collaboration with Nervi. In the context of São Paulo architecture in the mid-20th century, Vilanova Artigas was one of the most important architects, with significant impact and influence on modernist thought in Brazil. Research [Tagliari *et al.* 2017; Lorenzi 2017] has pointed out the gret importance of the *œuvre* of this modern architect, particularly in São Paulo. The significance of his work is not limited only to his architecture but it also encompasses his writings and teachings that have contributed to the formation of São Paulo and Brazilian architecture.
Combining the reading of the texts written by Vilanova Artigas and the analysis of his architecture, it is possible to identify important concepts present both in theoretical discourse and in design practice: I) search for new and varied forms and technical solutions; II) scientific, technical, and artistic experimentation; III) innovative character in the field of technique and science, especially in the exploration of reinforced concrete, with the structure as defining the architecture; IV) nationalist spirit in the creation, development,

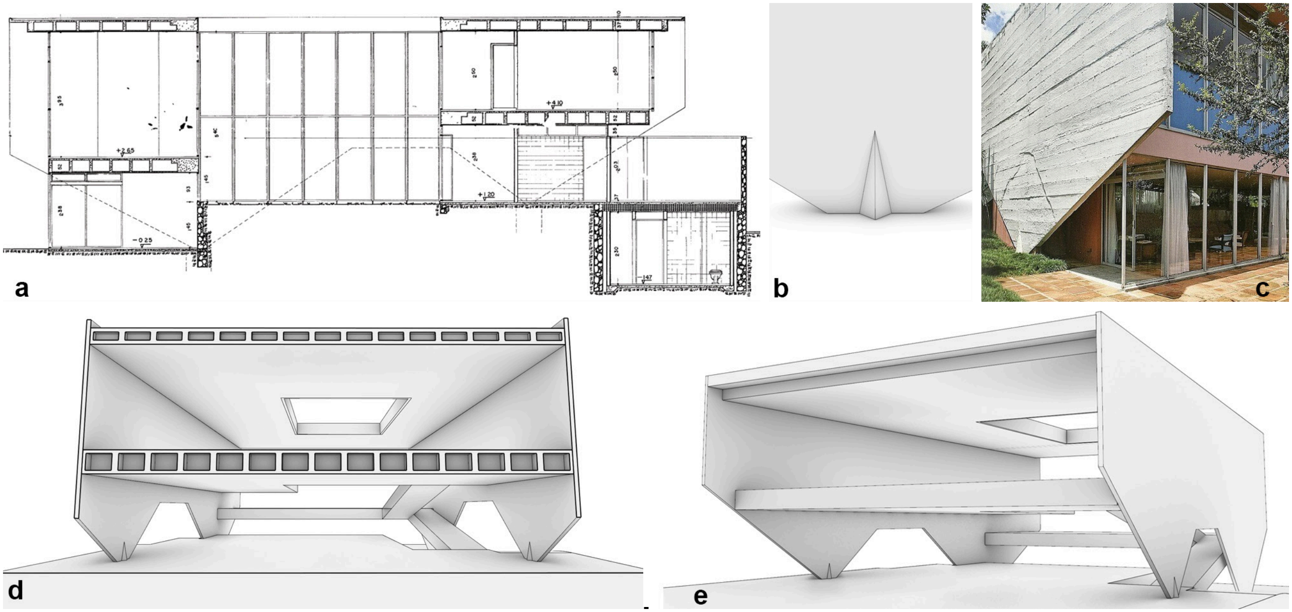

Figure 2. a. Original drawing of vertical section (source: Acervos da FAUUSP); b. detail of the pyramidal support in a portico (elaboration by the authors); c. photo (source: Acervos da FAUUSP); d., e. 3D structural model (elaboration by the autors).

and strengthening of an identity for an authentic São Paulo architecture; V) human environments that promote meetings and interaction or strengthen the collective and social character. As we well note further, for Vilanova Artigas, "in the structures, the findings in the formal Brazilian memory are synthesized today with the ardent desires for cultural independence, the pursuit of harmony and beauty so dear to our people" [Vilanova Artigas 2004, p. 140].

Research

"At first, we made our columns as concrete supports, hidden within walls that seemed load-bearing. Then we freed these columns and showed them as they were. Then we began to deny them in various ways, in countless ways: reducing their number to a minimum, removing them from the vertical, bending their pillar shape, and finally not using them at all" [Vilanova Artigas 2004, p. 136].

In this statement, the different proposals to make the column the very architectural expression of the building are clearly noticeable. Firstly, the columns are concealed inside the walls. Secondly, the construction of pilotis is proposed. The third involves constructing curtain walls, which resemble folds and exert tension on the structure. The fourth comprises lowering the number of columns to just four. In the fifth option, the columns are removed from their vertical position. In the sixth option, the portico's column is tilted. And finally, not using it, like in concrete boxes.
In the *Guarulhos Gymnasium* (1960), there are three types of exposed reinforced concrete columns made up of trapezoids (fig. 1). There are visible marks from the concrete formwork. The blue and red colors highlight the silhouette of the columns. The concrete slabs are exposed, with a finish that does not reveal the construction marks, while all the masonry walls are covered with plaster and paint.
In *Bittencourt II Residence*, Vilanova Artigas took even bolder risks in designing the apparent structure (fig. 2). Inspired

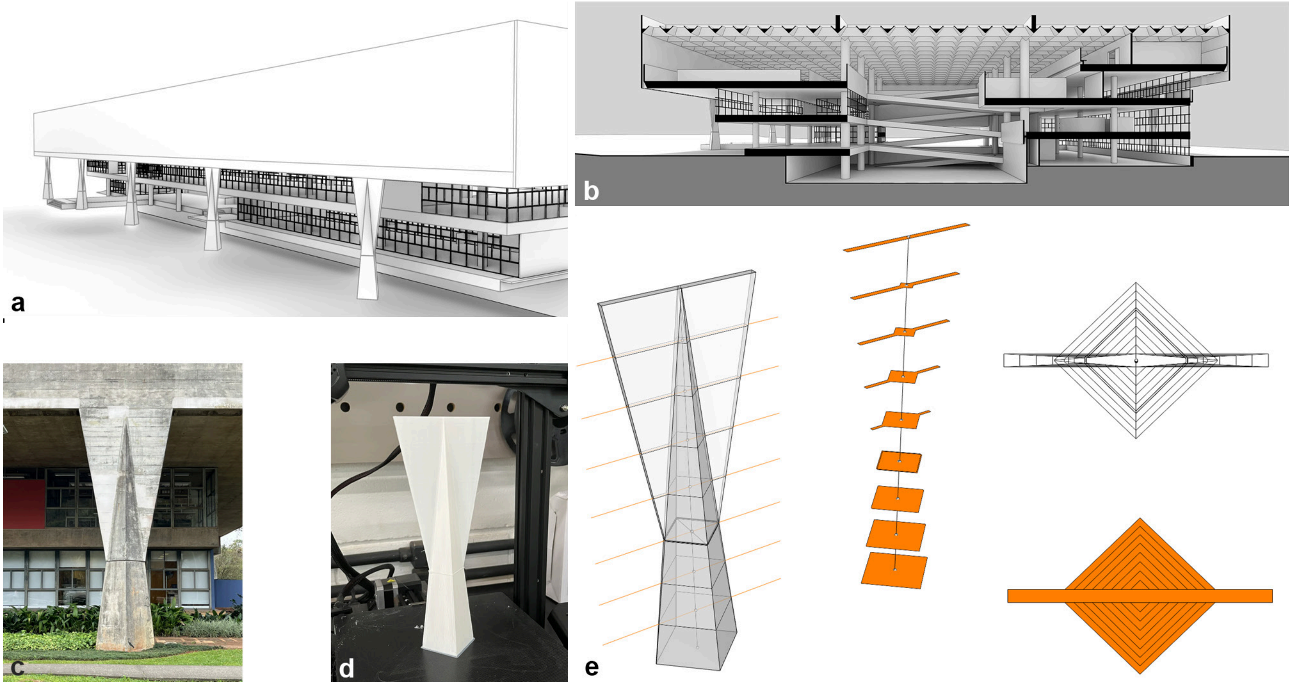

Fig. 3. a. Perspective drawing; b. vertical section; c. photo of the column; d. photo of the physical model; e. column geometry (elaborations and photo by the authors).

also by the boldness of Oscar Niemeyer's structures for the Palaces of Brasília (1956), Vilanova Artigas created porticos and columns that challenged the traditional precepts of the time, as one can note in this declaration: "What fascinates me is creating heavy forms and bringing them close to the ground and, dialectically, negating them. Transform my columns into things that, to the eyes of the demanding engineer, become something to say: This whole thing is going to fall apart!" [Vilanova Artigas 2004, p. 225].
In a challenging way, a small pyramid (20 cm wide by 50 cm high) with a square base intercepts a trapezoidal exposed concrete portico over an extension of 50 cm in width (fig. 2b), concentrating the entire load of the building on just 4 supports (2 on each side of the residence). In the photo of the portico (figure 2c), it is possible to notice the marks of the large concrete formwork boards.
The internal cylindrical columns of the Faculty of Architecture and Urbanism of the University of São Paulo (1962), FAUUSP (fig. 3), sustain the weight of the building's floors, whereas the external trapezoidal columns support the roof with trapezoidal beams. Both are exposed structures that elucidate the construction system.
Figure 3e displays variations in the cross-section along the vertical axis of the outer column. The geometry originates from the intersection of a square-based pyramid with a trapezoidal form. In the photo (fig. 3c), one can notice the marks of concrete formwork.
In this way, the column spacing contributes to establishing the building's length and width, whereas the beam establishes its height [Kahn 1957]. At FAUUSP, the external concrete column and beam efficiently sustain a great roof.
The building for the São Paulo Football Club Locker Rooms (1961) (fig. 4) was designed to have an exposed concrete structure. In figure 4a, the modulation of the concrete formwork boards in the drawing is noticeable, revealing the intentional marks left by the construction. As a part of the

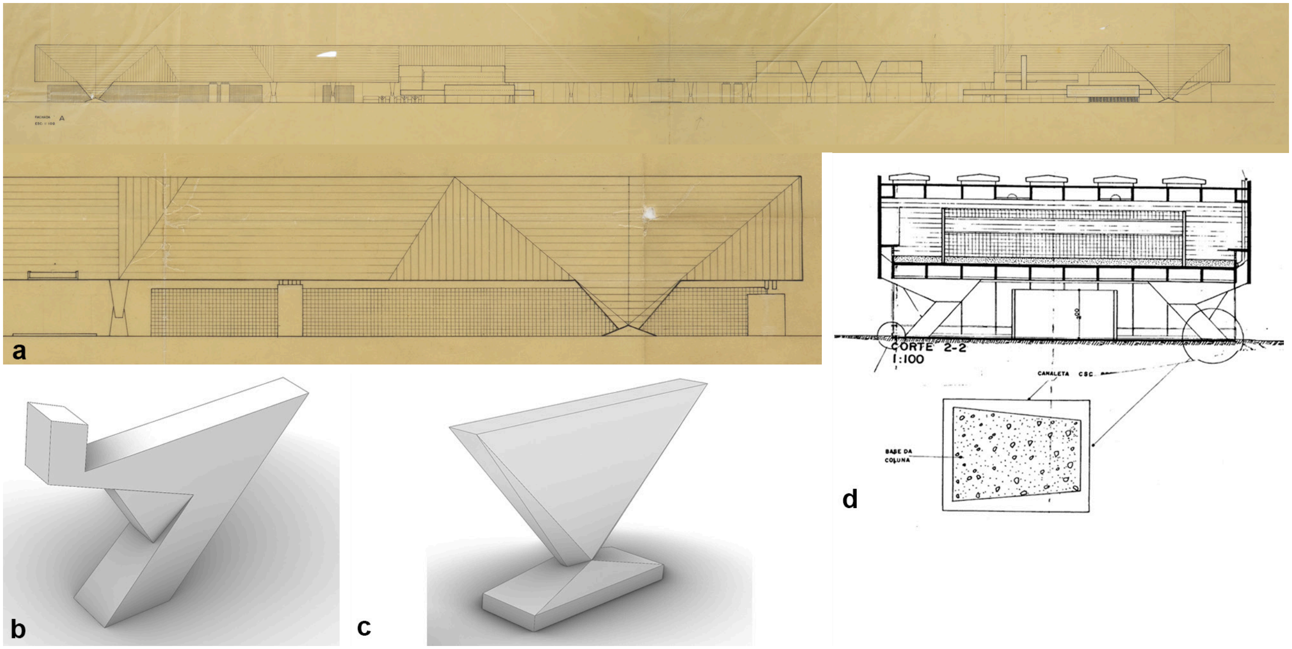

Fig. 4. a. Original drawing of elevation view (source:Arcevos de FAUUSP); b., c.: 3D digital model of columns (elaboration by the authors); d. original vertical section (source: Arcevos de FAUUSP).

portico, the sculptural columns transmit the weight of the building to the ground in such a way as to provide a sense of lightness and suspension. Despite having received a coat of paint, the concrete marks on the columns remain visible. The 'voids' between the triangular and trapezoidal faces in the columns of the sculptural porticos of the Anhembi Tennis Club (ATC, 1963) are a unique feature (fig. 5). The innovation was to create a rainwater collection system from the roof, which would channel the rainwater in a cascading manner from one gargoyle to another until it reached a receiving box in the ground (fig. 5f). This curious invention makes this portico unique, whose sculptural beauty arises from the interplay of light and shadow on its multiple faces. "This is the Anhembi Tennis Club. This portico is what ended up being called 'self-supporting' because it rests on one point, like the FAU column, and has a twenty-meter span to the other side" [Vilanova Artigas 2004, p. 229]. The significant weight of the porticoes at this end enables the tensioning of the slab. Both slabs and beams have a minimal thickness. In the ATC, the exposed concrete was well executed, without marks from the concrete boards, but it revealed its structure in an honest way. Eight trapezoidal columns support the Santa Paula Yacht Club Boat Garage (1961), which measures 15 m in width and 70 m in length, with a cantilevered structure of 10 m (fig. 6). In the elevation view, observers can see the horizontal lines that indicate how the boards of the exposed concrete formwork are arranged. The Santa Paula Yacht Club Boat Garage's technical drawings are impressive due to their meticulous construction and attention to detail.

Discussion

After all, what is the symbolism of a structural column and apparent concrete in architecture? For Vilanova Artigas,

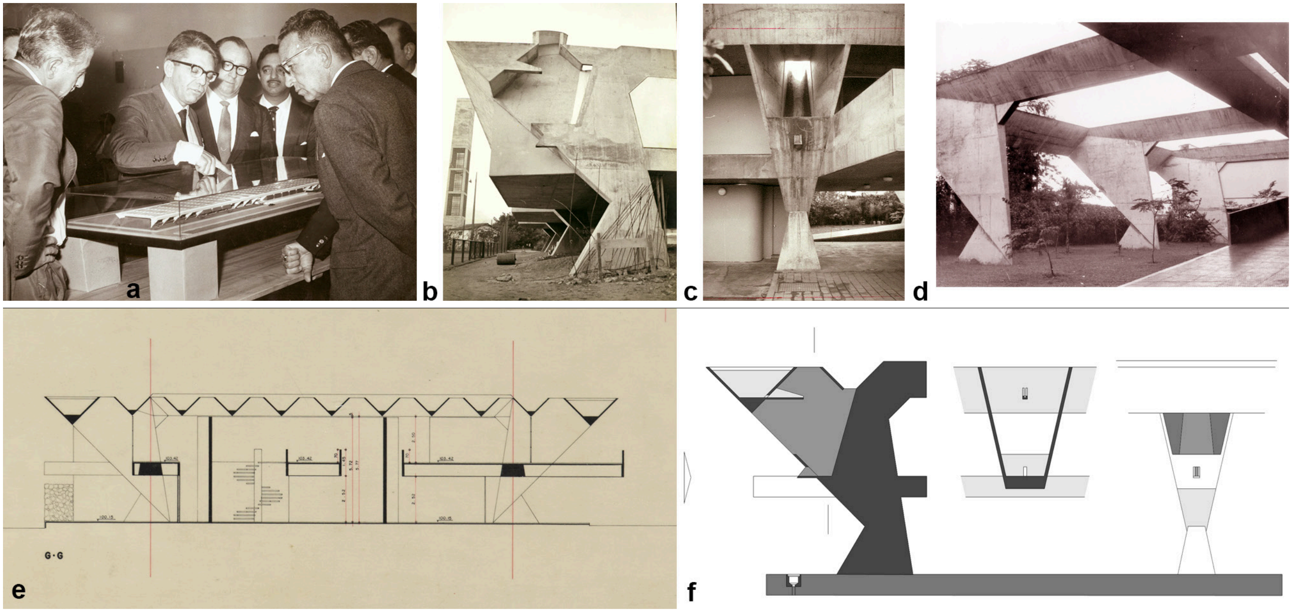

Fig. 5. a. Vilanova Artigas with the physical model (source: Acervos de FAUUSP); b., c., d.: photos of the porticos (source: Acervos de FAUUSP); e. vertical section drawing; f. redrawing of the portico (elaboration by the authors).

leaving the structure exposed meant revealing the truth of the construction, making it more honest, and achieving an immediate understanding of how it is produced. In the words pronounced by Le Corbusier: "and under the pilotis, which reclaim vast and sloping spaces […] these 'pilotis' that I speak of constitute a great achievement of modern techniques" [Le Corbusier 2004, pp. 56-58]. Furthermore, buildings suspended from the ground represented the achievement of technique.
But there is a quote by Kahn that reinforces a very important meaning of the constructive character: "Design habits leading to the concealment of structure have no place in this implied order […]. I believe that in architecture, as in all art, the artist instinctively keeps the marks which reveal how a thing was done" [Kahn 1962, p. 2]. Thus, the marks of the concrete formwork boards left on the exposed concrete surface highlight part of this construction process. Vilanova Artigas documented his vision of architecture in his texts, which clearly reflect his view as an architect regarding the relationship between architecture, technique, and construction.
The solution to technical problems arising from the creation of large spans and sculptural columns symbolized independence. In the words of Vilanova Artigas: "In the structures today are synthesized the findings in the Brazilian formal memory with the ardent desires for cultural independence and the search for harmony and beauty so dear to our people" [Vilanova Artigas 2004, p. 140]. Therefore, the visible structure symbolizes the proud professional and cultural ability to represent Brazilian architecture at that time.
As an engineer and architect, Vilanova Artigas sought to reconcile art and technique, daring in the creation of new ways to conceive and construct buildings. Beyond solving functional problems, aesthetic and psychological aspects were presented. We observe and experience the spatial environment surrounding columns in a building in complementary ways. Firstly, the feeling of lightness and floating in this structural element enables freedom to move. Secondly, the rhythms created by the columns encourage and guide our movement through the space. Thirdly, the scaling and proportion of the areas engender a sense of intimacy as we

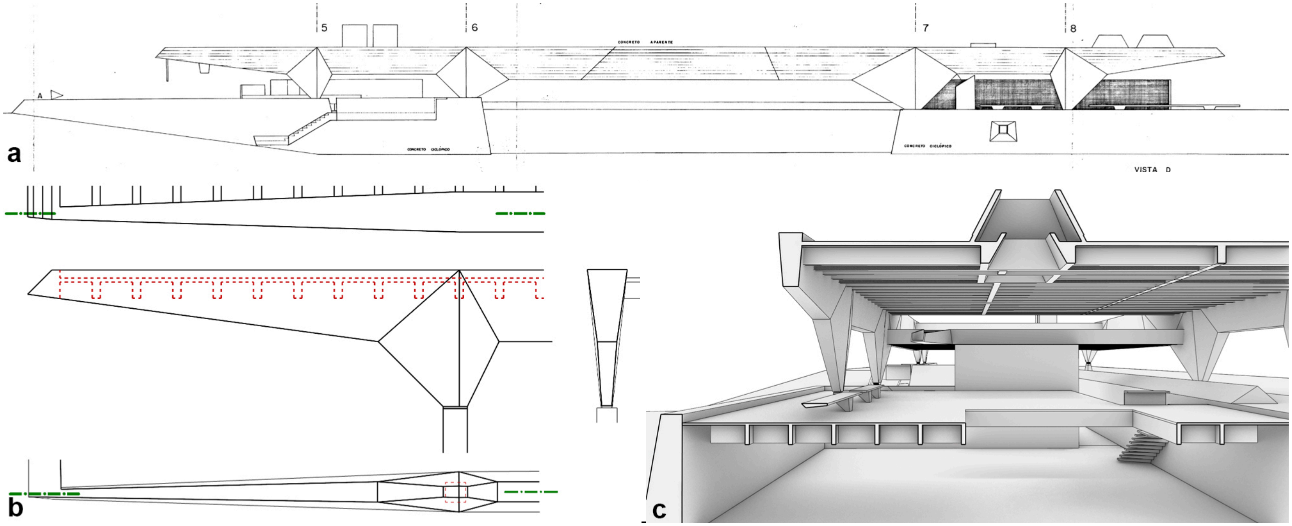

Fig. 6. a. Original drawing of elevation view (Acervos de FAUUSP): b. drawings of the details of the column 1; c. perspective section of 3D model (elaboration by the authors).

traverse them. Fourthly, there exists a juxtaposition between the solidity and robustness of the columns and the expansive space that envelops us. Consequently, the visible structure elucidates the architectural system in a lyrical manner. Vilanova Artigas typically designed structures characterized by a simplicity of forms, featuring monovolumes with a singular prominent roof that contrasts with the sculptural form of the columns. The primary emphasis is on the areas situated beneath the spans and covers. However, the delineated void, characterized by its limits, is equally significant as the functional areas. We considered the most sculptural column for the portico of Anhembi Tennis Club due to its interaction with technical issues, including both structural concerns and rainwater capture, as well as its aesthetic appeal.
In the '50s and '60s of 20th century, the detail in Italy were deeply elaborated by architects "in which the analysis and displays of material, provided by the laws of construction and formation of the architectural object, constituted its principal support" [Gregotti 1983, p. 496]. A similar situation occurred in Brazil with the main architects at the time. In addition to the cylindrical columns particularly designed at the beginning of his career, in the '40s, the columns and porticos created by Vilanova Artigas in the '50s and '60s can be grouped into two major groups: Block 1: a) trapezoidal columns; b) pyramidal columns; c) sculptural columns. Block 2: Porticos: a) trapezoidal with flat slabs; b) sculptural with slabs made of folds. Curvilinear columns, like those at the Jau Bus Station and the Technical School of Santos, are rare in his work.
We can affirm that the morphogenesis of the trapezoidal columns occurred mainly during the '50s and '60s. The projects presented here contain the lexicon of columns and porticos that constitute the foundation of Vilanova Artigas's structural and aesthetic thinking during this period. The plentiful opportunities to design projects related to different themes probably stimulated the architect to create innovative ways to support the buildings with extensive spans.
From columns made of pyramid trunks to sculptural porticos, the architect sought innovative ways to transmit the building's load to the ground, both technically and poetically. As one can see in figure 7, both the columns and the porticos are made up of sections formed by a geometry that varies along the structural piece, that is, the shaft. The shape of the sections varies between rectangular, trapezoidal, octagonal, or multifaceted variations.

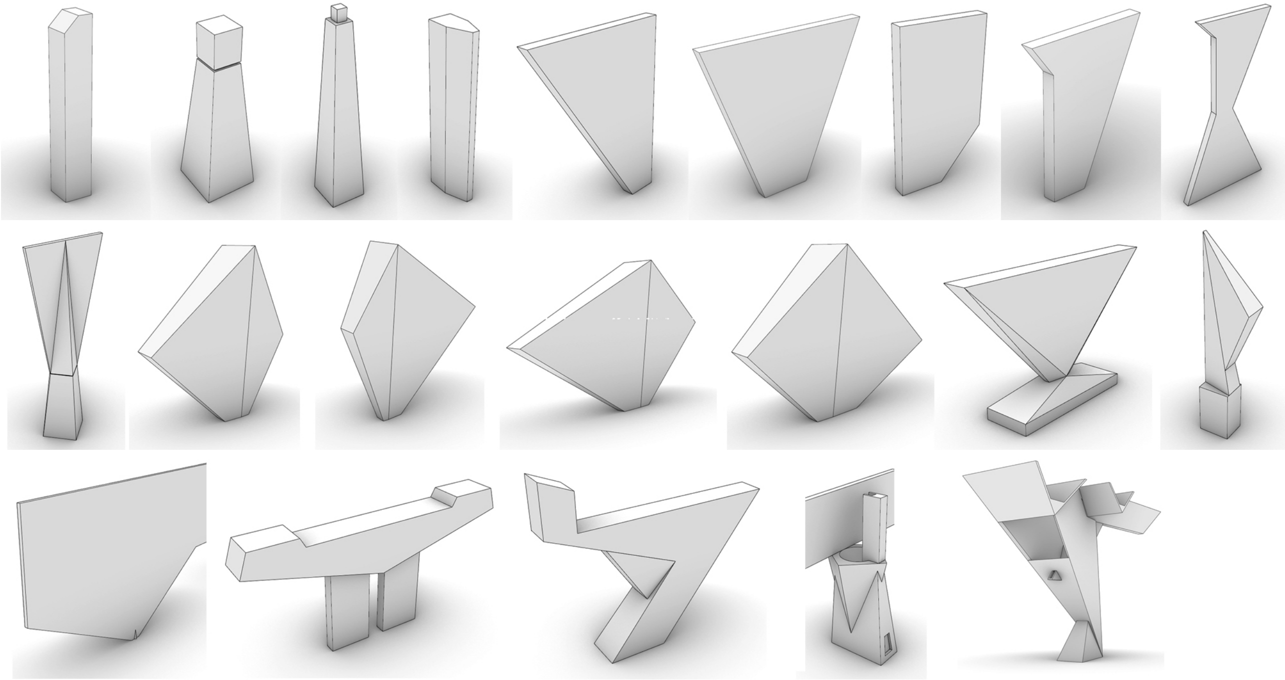

Fig. 7. The morphogenesis of the trapezoidal columns and porticos (elaboration by the authors).

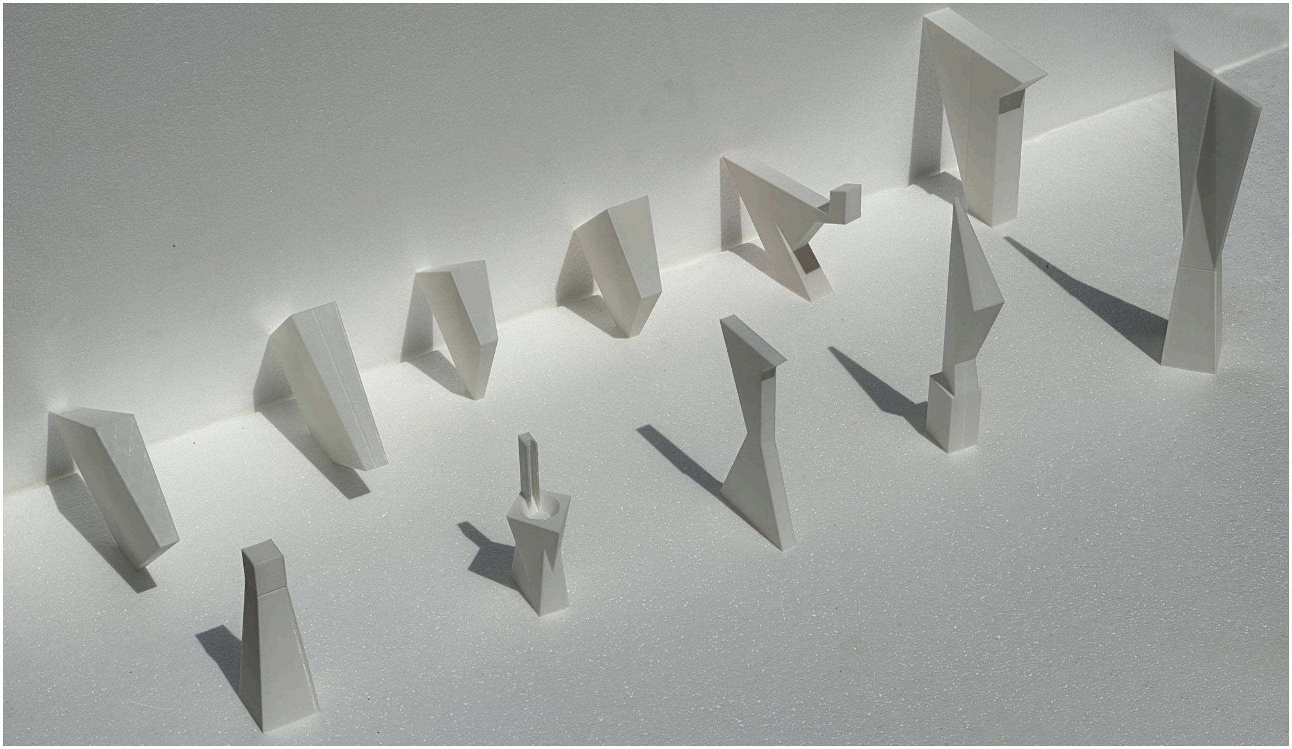

Fig. 8. Photos of the physical models (elaboration by the authors).

We also created three-dimensional physical models (fig. 8) to enhance understanding and offer a concrete experience of the aesthetics of constructive logic. Generally speaking, it can be stated that the external columns are more elaborate than the internal ones in Vilanova Artigas's works. Although both have structural purpose and performance, the sculptural external columns serve to contrast with the austerity of the monolithic volume of his buildings. In fact, the surfaces of the trapezoidal columns are typically smooth; however, the surfaces of the beams and walls of the supporting structures are rough, exhibiting discernible traces from the concrete formwork boards. It can be conclusively affirmed that the tenets of contemporary architecture are evident throughout Vilanova Artigas's oeuvre, especially his quest for the authenticity of construction and the ideal of creating humanized, communal, and democratic places.

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Sitography

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The Shell Structure of the Frontón Recoletos: from Design to Construction

Andrea Giordano, Andrea Colombo

Abstract

Shell structures, also known as laminar structures, profoundly influenced the design and construction mentality of the leading exponents of Constructive Rationalism in the first half of the 20th century. The structural art of designers like Eduardo Torroja, Pier Luigi Nervi and Félix Candela achieved its maximum aesthetic expression in this fascinating type of construction, which based static resistance on the shape of the structure itself.
This construction archetype –mainly influenced by the geometry and relationship of the structural elements– requires an accurate representation –both in the two-dimensional and three-dimensional spheres– of the spatial elements that compose the work. This is accom-panied by the practical aspect of construction, characterised by the use of concrete with the support of articulated ribs and formwork.
This article addresses the main aspects of laminar structures, to which Torroja contributed through the creation of some of his most famous works. The most audacious –both from an architectural and geometric-structural point of view– was undoubtedly the Frontón Recoletos and its roof, whose geometric and constructional peculiarities made the building famous worldwide. Much of the credit for the construction of the shell and its skylights is attributed to the engineer himself, who was responsible for the design, structural calculations and actual construction.

Keywords: Shell structures, geometric-structural configuration, representation of the construction.

Introduction

This contribution highlights the importance of geometry for the configurative and structural genesis of architecture. In this regard, it is interesting the multifaceted nature of the study of geometry, including analytic, euclidean, descriptive, and projective geometry, as well as Topolgy. In this sense, we begin with the elementary shapes and their properties developed in the euclidean context, which studies the assets of objects (planes and solids) that remain unchanged despite their rotations, translations, and reflections [Ugo 2020]. These properties include the congruence of segments that have the same length, the congruence of angles that have the same measure, and parallelism. Logically, in topology, we move to a more critical dimension of shape, since we leave aside measure and angles to include the concept of 'place' [Docci 2007].
These features are complemented by the theoretical aspects of descriptive and projective geometry, which are related to the representation and communication of architecture. For instance, projective geometry studies how objects are seen, also distinguishing between the real shape of the object and its appearance. In both cases, the study of surface genesis is fundamental [Carlevaris, De Carlo, Migliari 2012].
What I state since now highlights the role of Geometry in both creativity and visual communication: the first aspect is related to the creation of a surface, and the second is linked to the communication of this surface through its

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representation. These topics constitute the educational foundation of geometry: underlying the configuration of space, knowledge of the geometric theory is essential for the creation of innovative architectural/engineering structures. Therefore, an understanding of shapes is also crucial, since it is closely linked, to a large extent, to observation, and since it has fundamental implications for the actual possibility of creating complex configurations so that can be clearly communicated and understood.

The geometric representation of surfaces

The study of architectural theory is closely related to its implementation, with a strong connection between a conscious creative intuition and the precise physical reality that connects shape and structure. For this reason, geometric/structural awareness is essential to invent and precisely proportion an architectural surface. Moreover, the effectiveness and productive power of creative intuition is widely demonstrated and attested by the grandiose works handed down to us from the past, when contemporary scientific theories were completely unknown. indeed, today, the accuracy of modern digital systems, in continuous and progressive development, has allowed us to achieve outstanding results in the creation of ever more grandiose and audacious works.
But the geometric/structural idea –which allows us to efficiently decipher the cur-rent architectural surfaces, which are proposed every day by the unstoppable development of every aspect of construction activity– is the result of a harmonious fusion of personal inventive intuition and objective and realistic geometric genesis linked to the structure [Giordano 1999].
Fundamental, therefore, are the theoretical developments of geometry, with an intuitive response that enlivens them, diminishing their impersonal technical harshness, and making them more human and comprehensive. Meanwhile, theories based on formulas must offer methods of precise evaluation that are responsible for achieving maximum re-sults with minimum means, that is the ultimate goal and fundamental direction of all human activity. In this sense, an architectural work becomes a synthesis of configurational and structural aspects, where in-depth study and examination will be particularly useful to future architects, who must know how to design and proportion it in its general lines, so that it is efficient, significant, and, ideally, beautiful. This creates an opportunity to understand architecture in all its aspects (aesthetic, economic, social, and technical), especially in the field of the gene-sis of architectural shapes and therefore of load-bearing structures, which allow the construction of works of extraordinary scale [Colombo, Giordano 2022].
In architecture the geometric/structural component is essential. "Sia che l'uomo costruisse un semplice riparo per sé e la sua famiglia, sia che erigesse ampi locali dove centinaia di persone potessero esercitare il culto, commerciare, discutere di politica od assistere a spettacoli, egli ha dovuto foggiare certi materiali ed impiegarli in determinate quantità perché le sue costruzioni potessero resistere alla forza di gravità od altri pericolosi carichi" [Salvadori, Heller 1963, p. 18]. In this sense, it is important to ensure a shape that can support and resist to internal and external forces, yet conceived according to aesthetic criteria, which often impose more stringent requirements on the construction of structures than those of strength and economy. Some archi-tects and engineers of the XX century –such as Eduardo Torroja, Pier Luigi Nervi and Félix Candela– have created highly beautiful architecture in which the close connection between shape and structure is evident. It is equally obvious that, once the basic principles of geometric/structural genesis have been established, design and execution management are also straightforward, making it easy to draw on these experiences, systematize this knowledge, and come to understand how and why a modern structure functions/works.
The representation of surfaces, in its various expressive forms, therefore constitutes the necessary cultural and syntactic element of mediation and integration between reality and imagination, as well as a specific theoretical and technical production tool for architectural design.

Form-resistant structures

Form-resistant structures are unique geometric configurations in which specific curvatures allow for increased resistance without having to increase thickness. Solutions of this type have always been widely used throughout history. Examples of this innovation can be found in Antoni Gaudí's architecture, which repeatedly used the catenary arch and its harmonious geometries to support roofs. Evoking shapes already present in nature, the Catalan master's works

feature parabolic arches, whose shape blends perfectly with the structural solution [Benvenuto 1995].
From the 19th century, a revolutionary advance was made in the design and planning of vaults: the concept of graphic statics made it possible to obtain the cable-stayed shape of structures, working solely on compression and eliminating tensile and bending stresses. This solution was particularly favourable for constructions made with ceramic materi-als, such as brick and concrete. Regarding brick solutions, in Catalonia, the brick vault played a primary role in the construction of both industrial buildings and noble palaces, particularly those of Ildefonso Cerdá's Barcelona Plan [Ochsendorf, Freeman 2010].
Eduardo Torroja Miret, an engineer from Tarragona (Catalonia, Spain), was an undisputed master in the field of form-resistant structures, working in a fertile context of geometric and constructional innovations. During his early academic journey, Torroja developed a strong passion for the brick vault construction system. Thanks to his Catalan ancestry, he was deeply surprised by the great potential of this local construction technique, which he himself defined as "a typical product of this land, just like the carob beans of its fields" [Ochsendorf, Freeman 2010, p. 195] (fig. 1).
The secret of their stability lied precisely in their lightness, shape and softness [Maure 2004]. However, beyond purely aesthetic considerations, the practical aspect was and remains the greatest advantage of this type of construction. In his research inspired by vernacular architecture, Torroja used *bóvedas tabicadas* on several occasions to build his structures, both to cover relatively long spans and as a substructure for upper floors. All this was done without the use of any type of formwork, resulting in significant savings in terms of both time and money. In some circumstances, he even used them as formwork for the construction of laminar structures, like in the case of the Fedala water reservoir (Morocco). Formwork for the entire structure would have involved a considerable cost, given the amount of material required and the particular geometry of the work. For this reason, Torroja decided to build the support structure for the concrete casting using his beloved Catalan vault, whose versatility allowed him to achieve the desired shape without using formwork. For the roof, which would not be subject to hydrostatic pressure, it was decided to leave the structure light with exposed triple-leaf bricks [Chías Navarro, Abad Balboa 2005] (fig. 2).
This example is just the latest demonstration of how brick vaulted ceilings are metaphorically (and in practice) the structural solution for support and transition –as well as the precursor– of reinforced concrete shell structures. For Torroja, the adaptability of reinforced concrete laminas in their structure, as well as their monolithic nature and spatial continuity, made this roof solution one of the most beautiful innovations in modern technology and architecture [Maure 2004]. Furthermore, the slenderness resulting from their derisory thickness ensured a perfect correspondence between the interior space and the volume visible from the outside, so much so that the functional expression of the building revealed itself [Colonnetti, 1957].
These were years –the ones in which he operated– when designers aimed to enhance the aesthetic value of a piece of work by expressing its resistance capacity [Torroja 1957]. However, the adoption of a particular structural type was not dictated exclusively by engineering considerations. It was also influenced by other fundamental functional reasons, primarily the construction process, which was closely linked to the economic feasibility of the project. This last consideration allows us to introduce another figure who was central to the development of this theme and who found himself interacting and discussing ideas with Torroja on more than one occasion: Pier Luigi Nervi, who, in the strictly constructive field, was able to fully orientate the formal conception of his structures. Nervi mastered reinforced concrete with great skill, which allowed him to optimise the cost of the

Fig. 1. Construction of Catalan vaults for the Sagrera Market in Barcelona [Torroja 1957, p. 280].

Fig. 2. Fedala water reservoir, Torroja, 1956: exterior view (up) and detail of the intrados with Catalan vault (down) [Torroja 1957].

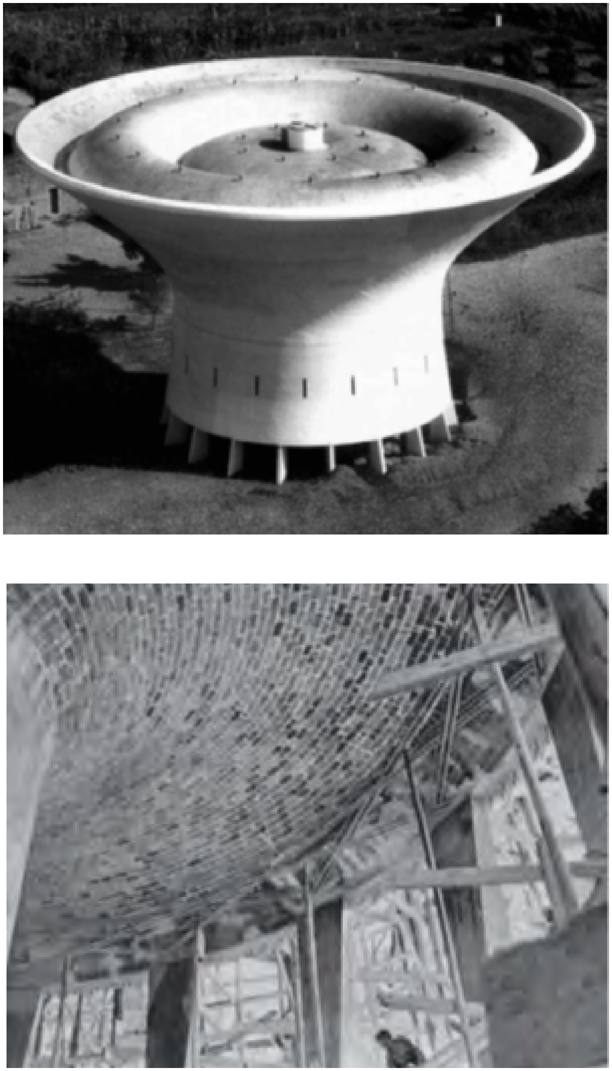


Fig. 3. Comparison between the intrados of the roof of Mercado de Algeciras (up) by Torroja and the Palazzetto dello Sport of Nervi (down).

work and rationalise the construction process, so much so that in the years that followed he was recognised not only as a "great sculptor of architectural spaces", but also as a "magician in the exhaustive control of the cost of the work" [Cassinello Plaza 2006, p. 28].
All this without ever ignoring the question of aesthetic expression, which had to be based essentially on the 'truth' of the architectural work. The structure had to comply perfectly with static requirements, allowing the forces involved to be visibly materialised. In this respect, Nervi probably proved to be more effective and consistent, as the ribs on the underside of his roofs perfectly reflected the transmission of loads to the ground. A comparison of two works by the authors clearly highlights this difference. Nervi's Palazzetto dello Sport, built in 1955, 22 years after Torroja's Algeciras Market, while still featuring a spherical dome roof, has a network of ribs on the underside that declare the Italian engineer's firm intention to transfer the loads to the ground. Torroja, on the other hand, seems to want to hide the stress of his roof, concealing the lines of tension that run inside it (fig. 3).
Indeed, the Spanish engineer seems almost to take a step back from considering architectural truth as an absolute and exclusive dogma, declaring that "while it is true that lying is sinful, hiding the truth is not always a sin" [Torroja 1957, p. 248]. In several cases, Torroja prioritises the concept of functional truth over structural truth, according to which there must be a perfect correspondence between the internal space and the volume visible from the outside, so that the functional expression of the work can be easily understood [Colonnetti 1957]. According to him, this is the type of construction that best reveals the nature of the building to the exterior, as well as the architectural features that are evident inside it. In such structures, the boundary between interior and exterior is so thin that it is difficult to speak of the intrados and extrados of the surfaces.
Similarly, an artist capable of creating works whose slender projections were almost 'negligible' in thickness was certainly Félix Candela, who was firmly convinced that in a building, beyond mere numerical calculations, there was a strong connection between form and structure. Candela found Mexico as the ideal environment for developing his challenging shell structures. The extremely favourable climate allowed him to overcome problems related to thermal insulation and waterproofing, while the low cost of labour favoured reinforced concrete solutions, given the complexity of the formwork. At the peak of his career as a builder, he took the 'umbrella' structures designed by Giorgio Baroni as ref-erence and, with the geometry of the hyperbolic paraboloid, he improved their execution. The main characteristic of this surface –as well as the hyperboloid– is that it appears concave in one direction and convex in the orthogonal direction. This dual orientation gives them a high aesthetic value: their sections and shadow lines give rise to the formation of ellipses, circles, parabolas, hyperbolas or straight lines depending on their orientation, with a gradual transition from one to another as the light changes [Torroja 1957]. From a construction point of view, the advantages of these surfaces are that the formwork is easier to install, as the boards used to contain the concrete must be arranged along the straight lines that generate the shape (fig. 4).
In the works of Torroja, Nervi and Candela, geometric-configurative design and structural framework were in perfect symbiosis. The artistic form and structural layout merged into a single whole, eliminating purely ornamental elements and enhancing, in their simplicity, the grace of the lines, the proportion of the masses and the rhythm of the openings [Torroja 1957].
Despite their purely engineering education and background, their design philosophy was perfectly in line with the principles promoted by the Modern Movement. The engineer Torroja became the spokesperson for these concepts, expressing them repeatedly in his works through a style based on the absence of elements. According to his conception of structure as a piece of art, its beauty had to be based on the rationality of the structure. Such splendour had to be achievable without the need for additions or external ornamentation [Colonnetti 1957]. Torroja believed that aesthetic value lay in the functionality of its structure, endowed with a rich static expressiveness. All these principles were reflected in the nude intradoses of his laminar structures which, except in cases of functional necessity, remained pure and free of ribbing or cladding material.

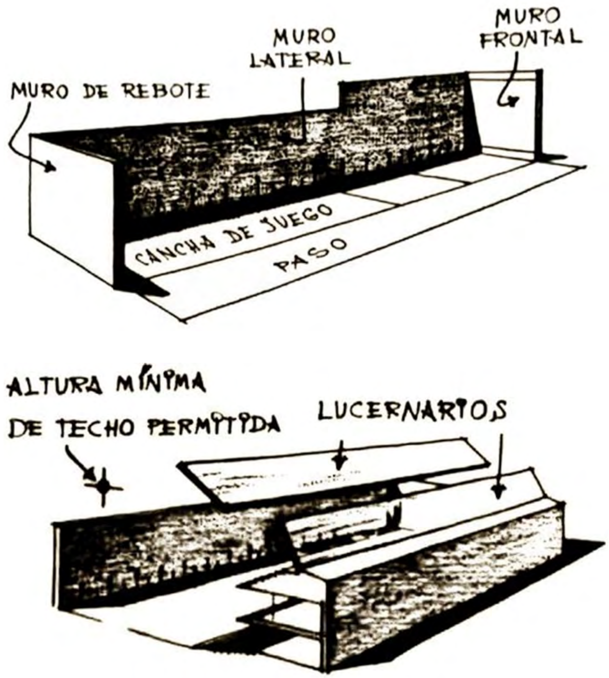
The gesture

At the beginning of the 20th century, the ideology of purity of the Modern Movement went side by side with those of dynamism and movement promoted by avantgarde

Fig. 4. Preparation of the casting for the roof of the Los Manantianales Restaurant, Félix Candela, Xochimilco, Mexico [Casinello Plaza, 2006].

currents, like the italian Futurism and russian Constructivism. These styles were constantly searching for expressions of energy and dynamism through sketches, drawings and architectural configurations. In the early days, this gesture was translated into a variety of barely hinted signs: strong gestures and strokes in Futurism, forced perspectives and unbalanced compositions in Russian Constructivism, accompanied by violent diagonal movements [Frampton 1986].
In Torroja, as in Candela, the gesture emerged spontaneously from an encounter between function and control of construction techniques. The functional solution activated the gesture, while the constructional mastery endowed it with security and firmness, as well as the desire for expression definitively guided the pencil. The gesture was integral because it was based on function and construction even before generating form. And once constructed, this form totally delineated the space, giving it a meaningful character.
Even the roof of the Frontón Recoletos sports hall – one of Eduardo Torroja's most recognisable works– was born from a clear and recognisable gesture. The structure and shape of this roof perfectly expressed the vaulting, physical violence and movement that athletes performed when hitting the ball. At the same time, it conveyed the energy and speed characteristic of the Modern Movement and the 'machine age' [1] [Salvadori, Heller 1963].
From the very first pages of the book *Razón y ser de los tipos estructurales*, it is clear that Torroja always associated the creative process through which he developed his buildings with an artistic process, linked to intuition and acquired experience. Theoretical study and technical-scientific education were limited to checking the forms and proportions that he had already assigned in advance. It is therefore clear that the creation of an artefact is not achieved deductively, through logical reasoning. To achieve the perfect form, Torroja worked by bringing together the starting conditions, from which he then conceived the geometry through intuition, imagination and pencil. It was an experimental approach in which calculation was relegated to a final tool to confirm the validity of the form obtained, where technical mastery was the support for the expression of the idea [Artieda, Machin 2013].
In the case of Frontón Recoletos, the initial constraints imposed on the roof were closely linked to the

Fig. 5. Frontón Recoletos: design constraints for the roof [Torroja 1962].

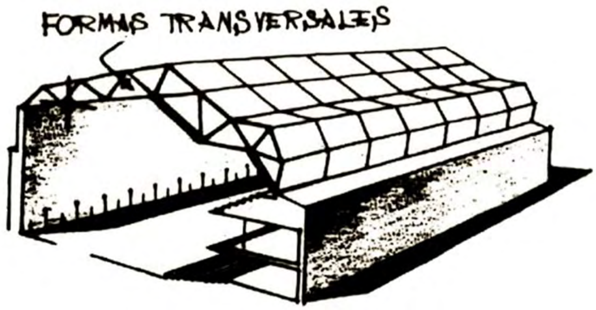


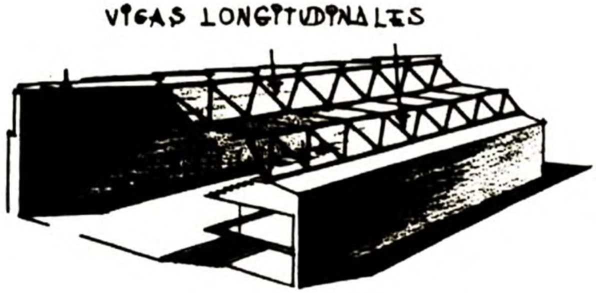
requirements of the sport, which also determined the geome-try of the playing field. Modern *pelota* vasca is a discipline that was played in a *frontón* enclosed by front (*frontis*), side (*pared de izquierda*) and rear (*muro de re-bote*) walls. Spectators occupied the fourth side, which was open and located opposite the side wall. In addi-tion, local regulations imposed a minimum height for the roof, justified by the minimum heights that the *frontón* walls had to have. This requirement allowed the *pelota* to trace its harmonious curvilinear trajectories without encountering any kind of obstacle (fig. 5).
As a first solution, the possibility of incorporating the two skylights into a multifaceted glass and steel roof was evaluated. The design involved a series of trusses joined together by longitudinal joists. However, the solution was not satisfactory for both aesthetic and structural rea-sons (fig. 6).
The second proposal, on the other hand, consisted of placing two large truss beams, leaning on the gables at the edges, through which indirect light could filter. The beam was therefore composed of a pair of crossbeams connected to each other by a network of diagonals (fig. 7). However, this option was not ideal either, especially from an aesthetic point of view. During the creative process, however, something completely spontaneous and irrational happened that led to the final design of the shell. The lines of the roof were softened, and the profile took on a curved shape. Always taking into ac-count the height and lighting requirements of the room, as well as the desire to convey a feeling of maximum spaciousness, the hand of imagination instinctively tra-ced two arches whose asymmetry coincided with that of the room itself. The idea took shape with the adop-tion of a cylindrical reinforced concrete lamina with two lobes which, at the skylights, was converted into a trian-gular mesh of glass panels [Torroja 1999] (fig. 8).
The system defined by the final design was therefore characterised by a cylindrical reinforced concrete shell only 8 cm thick, which doubled (16 cm) at the orthogo-nal intersection of two cylindrical lobes, generating the so-called 'gull-wing' section. The new shape was thus born from a gesture: it expressed the movement of the athlete hitting the ball and at the same time conveyed the dynamism of the machine. The new concrete so-lution was the ultimate expres-sion of the concepts of horizontality, speed, strength and nudity [Artieda, Ma-chin 2013] (fig. 9).

Fig. 6. Frontón Recoletos. First project proposal: po-lygonal roof [Torroja 1962].

Fig. 7. Frontón Recoletos. Second project proposal: truss beams [Torroja 1962].

Fig. 8. Frontón Recoletos. Permanent solution with asymmetrical lobes and triangular mesh skylight [Torroja 1962].





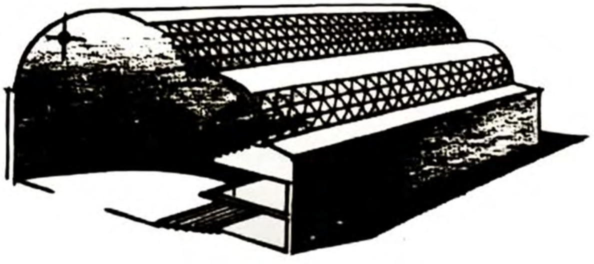
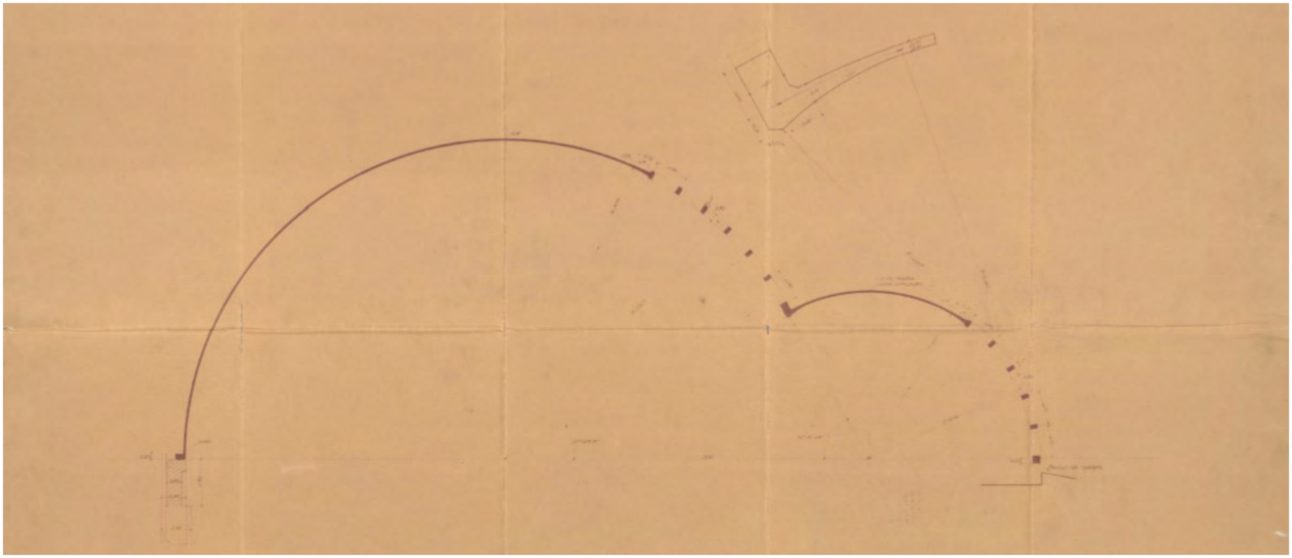
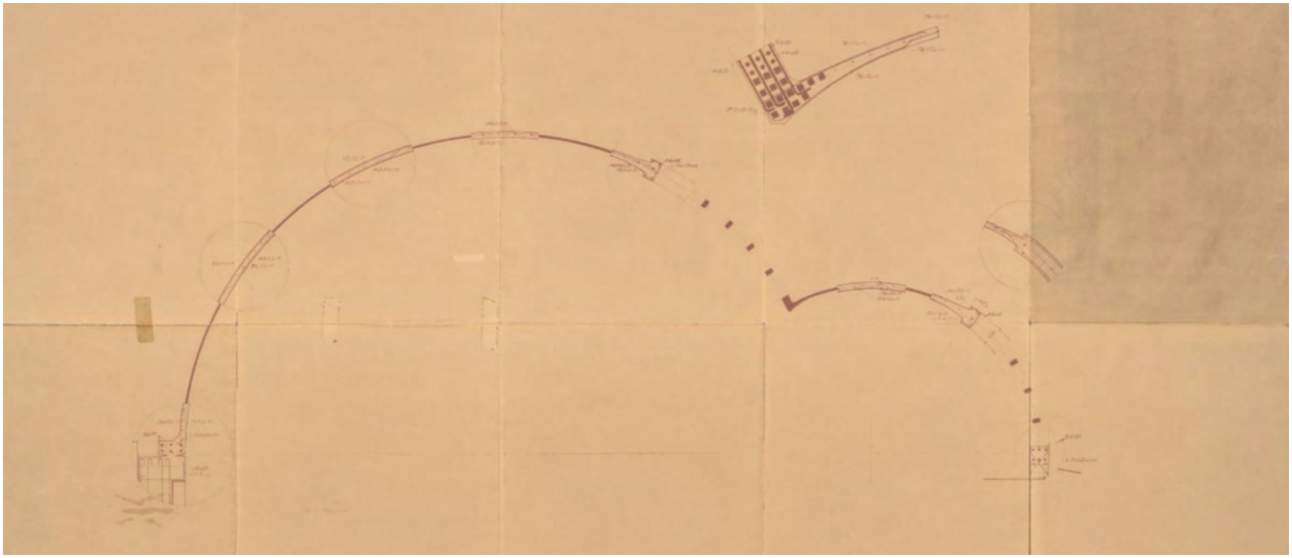


Fig. 9. Frontón Recoletos: cross-sections of the roof. Concrete and reinforcement drawings [Archivo Digital Torroja, CEHOPU-CEDEX].





From the paper to the construction site

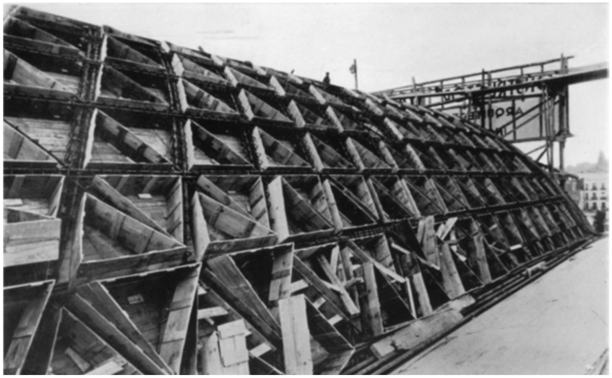
Engineer José María Aguirre Gonzalo and professor Eugenio Ribera were called in as consultants to assess the structural feasibility of the audacious roof. The two structural experts produced a dozenpage report setting out their observations on the construction of the roof and the installation of the ribs for working at height [Ribera, Aguirre 1935]. Specifically, it was suggested that a horizontal ribbing be erected with the relevant sup-port struts; that the formwork be removed carefully, together with monitoring of any deformations produced once this operation had been carried out; and finally, that an external layer of insulation be added to prevent excessive thermal fluctuations in the concrete.
From a construction point of view, for this type of roofing it was necessary for the lamina to behave as uniformly as possible. The casting of the concrete mixture therefore had to be simultaneous, without any repeated pouring. This inevitably led to a disproportionate consumption of timber, not only for the props, but also for the formwork. In fact, even though it was a series of repeated modules, it was not possible to take advantage of reusing the formwork from the previous casting. The choice was also dictated by the need to complete the work and start business as soon as possible, given that the income generated by the first sport events, according to the client's calculations, should have covered the excess costs. It was therefore decided to use quick-setting alumina cement in order to further speed up the construction time. The cast-ing was then carried out in less than a week. Once hardened, the ribs were carefully removed under strict control of the deformations of the lamina, which were found to be in conformity with the calculations [Arredondo Verdu et al. 1977] (figs. 10, 11).

Conclusions

The essay clearly demonstrates how drawing and geometry are essential tools for the development of a design idea. In particular, drawing in the form of a sketch, or as a support for the elaboration of a drawing, represents the pivot around which the entire development of an architectural and structural concept revolves. In the circumstance of Frontón Recoletos of Eduardo Torroja, the engineer, translates his thoughts onto paper in the

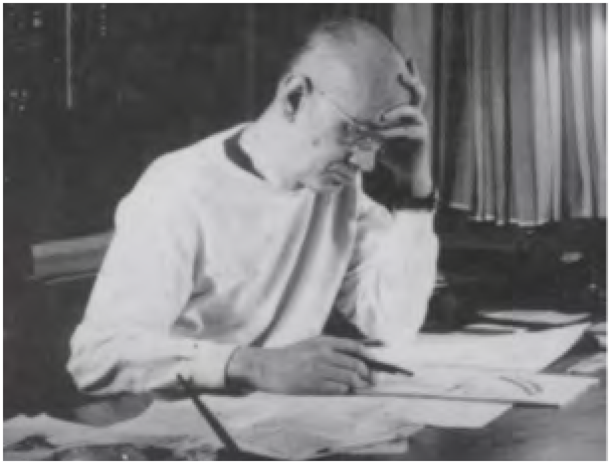
Fig. 10. Frontón Recoletos: overview of the construction site layout [Liñán 2020].

Fig. 11. Frontón Recoletos: the placement of formwork on the main vault. [Martínez Martínez, 2018].



form of diagrams, gathering his reasoning and sharing it with the observer. We talk about transparency of structure –provided by the monolithic solution of concrete shells– but we also and especially talk about transparency of thought.
Through paper and pencil, the author takes us into his imaginary world and allows us to participate in the creative process, offering us the key to access and understand the path that led to the final conception of the work. The sections of the project, on the other hand, offer an insight and appreciation of the engineering effort behind the curtain of the architectural envelope. In this case, the geometric design acquires graphic and technical value, representing the manual for the effective realisation of the work.
The interesting aspect of laminar structures is the lack of distinction between structural consistency and geometric-architectural configuration. This is even more evident in the graphic production of the designs, in which the visual description of the load-bearing element takes on both aesthetic and constructive value (fig. 12).

Fig. 12. Eduardo Torroja, "solo et pensoso".



Notes

[1] The term 'machine age' refers to the aspects of energy and dynamism, key elements of the Modern Movement and related architectural trends. In addition to these elements, there is the concept of the 'Machine for Living in', repeatedly proposed by the architect Le Corbusier.

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Parametric Architecture: the American Visions of Vittorio Giorgini

Alessandro Meloni, Denise Ulivieri, Marco Giorgio Bevilacqua, Piergiuseppe Rechichi, Zhangliang Shuai

Abstract

This paper analyses the American work of Vittorio Giorgini (1926-2010), a Florentine architect who, starting in 1969, found in New York the ideal context for developing visionary and experimental research. The study focuses on the projects Walking Tall *(1982-1983) and* Hydropolis *(1981-1982), emblematic examples of an architectural language that combines geometric rigor, structural experimentation, and strong expressive intensity. In these works, geometry acts as the generative principle governing form, structure and function, anticipating approaches that can today be associated with parametric thinking. Through the analysis of archival drawings and manuscripts, the research identified the elementary geometric units and the aggregation logics underlying the projects, translating them into dynamic digital models through VPL (Visual Programming Language) procedural modelling tools. This method made it possible to validate the consistency of Giorgini's design grammar, confirming its relevance and translatability into flexible generative systems. The digital reconstruction does not operate as a mere reproduction, but as a testing environment capable of verifying the feasibility of the proposals, transforming utopian vision into operative hypothesis. The paper thus highlights the anticipatory value of Giorgini's research, a still under-recognized figure who combined geometric experimentation, attention to the urban context, and the aspiration towards alternative models of the city, and who can today be considered among the forerunners of parametric architecture.*

Keywords: Vittorio Giorgini, archival drawings, procedural modelling, Visual Programming Language, geometry.

Introduction

This paper examines the work of architect Vittorio Giorgini (1926-2010) during his American period, with the aim of shedding light on innovative and forward-looking projects that still remain under-acknowledged today. Giorgini spent the first part of his life in Florence, but from 1969 onward he found in the United States the most fertile ground for his research and design work. Building on existing studies [1], it is now possible to start a research focused on Giorgini's American architectural production, consisting largely of unbuilt projects preserved in archives [2], which reveal a strong expressive and constructive originality. His proposals combine a provocative, unconventional language with a rigorous geometric structure based on principles of proportionality and fundamental geometric operations, an approach rooted in architectural culture which, although conceived in a pre-digital context, anticipates methodological principles now associated with parametric design.

The aim is to enhance this heritage through virtual modelling, grounded in the analysis of sources and theoretical principles. The study of archival material makes it possible to investigate Giorgini's design methods and the theories underlying his architectural forms, in which structure determines the overall expressive character and emerges as the outcome of a sophisticated geometric system, even though not always explicit. The digital reconstruction is

based on the interpretation of these geometries through parametric strategies designed to generate dynamic, implementable, and constantly evolving structures. The use of VPL (Visual Programming Language) tools enables the investigation of constructive principles and confirms the contemporary relevance of Giorgini's research.
The paper therefore represents an opportunity to rediscover a remarkably significant designer who, although not completely understood by his contemporaries, appears today as a precursor of approaches central to contemporary architecture. The New York projects *Walking Tall* (1982-1983) and *Hydropolis* (1981-1982) embody the essence of his American experience: works with strong expressive charge and dynamic forms, situated on the boundary between architecture and art. In these projects, the design process fuses architecture, engineering, and the visual arts, generating a language that assumes sculptural qualities transposed into architectural form.

Giorgini: a florentine architect in New York

Vittorio Giorgini was born in Florence and grew up in a culturally and socially stimulating environment. At Villa Torrigiani his father Giovan Battista (1898-1971), a key promoter of Made in Italy worldwide, organized in 1951 the first Italian high-fashion event for the major American department stores market [Fadigati 2023]. At that time, Vittorio was twenty-five years old, actively assisting his father while studying at the Faculty of Architecture in Florence. From his university years onwards, his research focused on the 'question of the model in nature' and its application to architecture, not as literal imitation, but as a means to achieve more efficient and effective complex systems. His explorations ranged from the study of curved systems such as shells and membranes to an interest in tensile structures, and to the geometric analysis of tetrahedral and octahedral forms.
Following this intense research, Giorgini coined the term 'Spatiology' to define his morphological studies in which he investigated the ways, the economies, the workings, and thus the relationships between forms and static systems of resistance, the constitution of matter and its functions [Giorgini 1995; Giorgini 2006].
After graduating in 1957, he combined professional and academic work, collaborating with Leonardo Savioli (1917-1982) and Giuseppe Gori (1906-1969), and developing a strong intellectual bond with Giovanni Michelucci (1891-1990). To this period belong his two iconic architectures – Casa Esagono (1959) and Casa Saldarini (1962)– both built in the Gulf of Baratti, only a few metres apart, where he had the opportunity to apply principles derived from the morphology of natural sciences to architectural design [3].
Growing disappointment within the faculty and bitter professional dissatisfaction at the failure to complete many projects prompted him to emigrate to New York in 1969, where he became a professor of design at the Pratt Institute School of Architecture. He fully immersed himself in the artistic and cultural life of what Koolhaas called the capital of 'permanent Surrealism' [Koolhaas 1978], building relationships with architects, artists, and intellectuals including Isamu Noguchi (1904-1988), Priscilla Morgan (1920-2014), Buckminster Fuller (1895-1983), John Maclane Johansen (1916-2012) and Robert Rauschenberg (1925-2008) [4].
His American projects are paradigmatic of his lifelong research. From the mid-70s onwards, Giorgini adopted construction systems based on triangular geometric configurations, linked to tetrahedral and octahedral space-frame logics, offering superior structural, formal, functional, and technological performance. He realised, in fact, that "in the study of nature […] ultimately, systems, even those that did not seem so –were based on triangular geometries" [Giorgini 2006]. Although fully aware of the transition from the age of mass media to that of computers, his structural and organic research led to proposals that were largely left unbuilt, often misunderstood, and labelled by critics as informal or excessive. His projects were grounded in a radical trust in technology –still too expensive and not yet standardised at the time [Ulivieri et al. 2022b; Ulivieri 2025]. They constitute key documents for understanding how static force diagrams and geometric models could be translated into architecture, as theorised in his major book 'Spatiology'. *The morphology of the natural sciences in architecture and design* [Giorgini 1995].

Visionary structures: space, geometry, architecture

The reference to Sigfried Giedion's seminal text *Space, Time and Architecture: The Growth of a New Tradition.* [1941], centred on constructive and spatial systems capable of inaugurating a new technological tradition, provides a useful framework for contextualising Giorgini's research. The Florentine architect imagined a future based on innovative

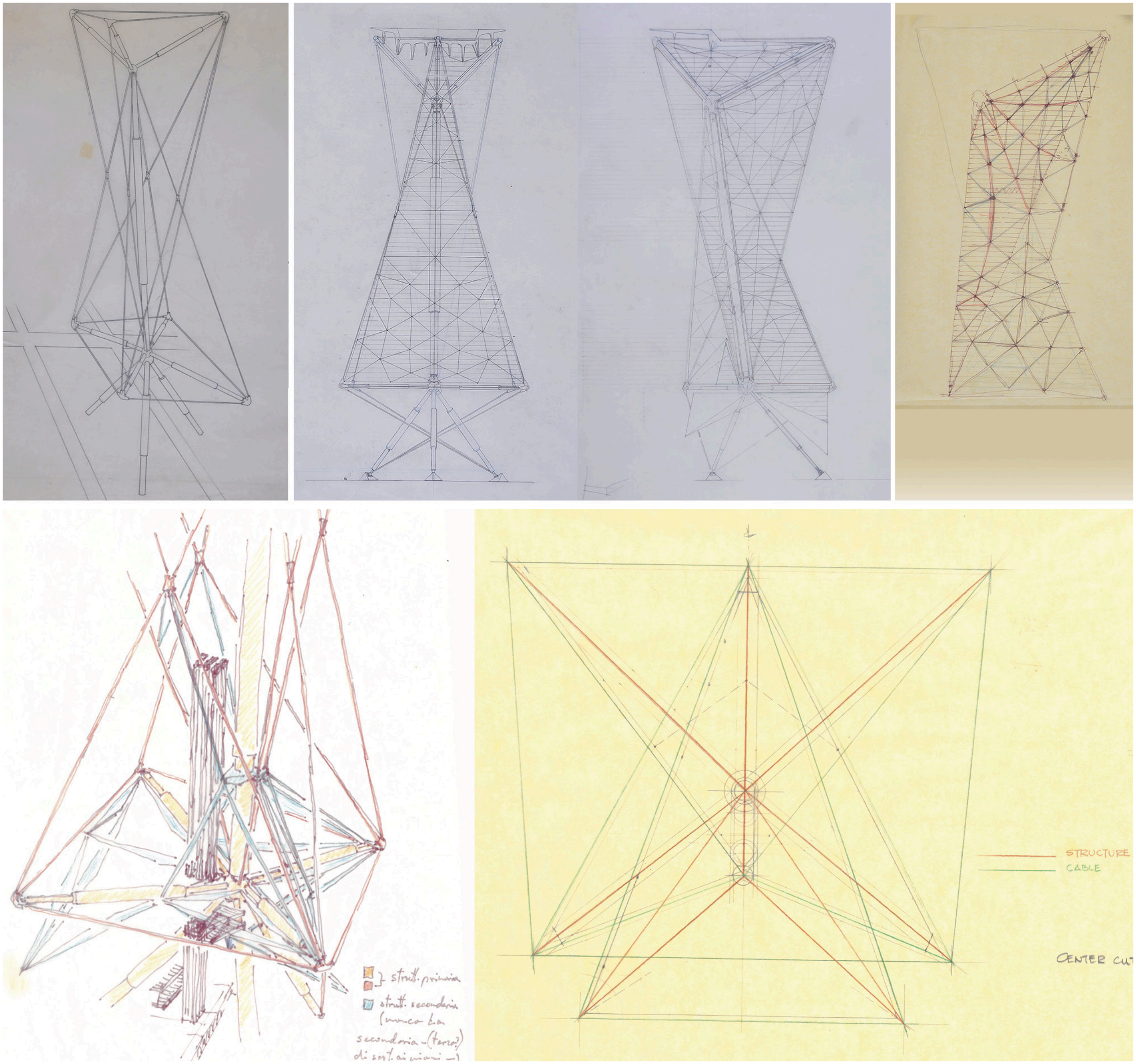


Fig. 1. Walking Tall: geometric composition and structural elements (B.A.Co.-Vittorio Giorgini Archive).

principles able to define an unprecedented architectural language, supported by rigorous geometric foundations and strong communicative value. His design visions, utopian in some respects, as many remained unbuilt, were based on spatial regulating structures capable of generating architecture and adapting to different scales and functions. Although highly original, Giorgini was not an isolated case: his experiments were part of a broader cultural landscape shared with contemporaries such as Yona Friedman (1923-2019), Paolo Soleri (1919-2013), Moshe Safdie (1938) and Anne Tyng (1920-2011) [Sky, Stone 1976], with whom he shared methodological and conceptual affinities, as well as connections in the art world. His work can be interpreted along two apparently contrasting design trajectories, recognisable in his early buildings: Casa Saldarini and Casa Esagono. The former is characterised by an organic quality, although Giorgini rejected this label, while the latter displays established geometric rigour. This dialectic reflects the broader tensions of contemporary architectural culture. Despite the diversity of formal expression, geometry remained the foundational core of Giorgini's research, developed through the medium of drawing as a privileged expressive tool. His representations were primarily bi-dimensional, plans, elevations, sections, with only occasional use of axonometric views, while the physical model was entrusted with conveying three-dimensional form, often with a pronounced sculptural character. The complexity of these topics suggests that the analysis began with his Italian houses, which already foreshadow concepts later developed more fully in his American work.
The adoption of experimental design solutions also reveals meaningful connections with contemporaries such as the Italian architect Dante Bini (1932), inventor of the spherical Binishell structures –an innovative construction system for building hemispherical concrete shells via pneumatic inflation [Pennacchio, Ricci 2018]. The affinity with Giorgini lies not so much in formal outcomes, but rather in shared experimental attitudes and the exploration of the potential of concrete in thin structures. This approach is clearly visible in Casa Saldarini, where a material as heavy as reinforced concrete is shaped into a light, sculptural form that subtly evokes nature. The project reinforces a key aspect of the period: the search for new construction technologies able to overcome the static, sceptical attitude towards innovation still dominant at the time [Giorgini 1995]. Conversely, Casa Esagono marks an early step towards a fully geometric conception of architecture. Its formal rigour aligns the project with key figures of structural engineering, such as Konrad Wachsmann

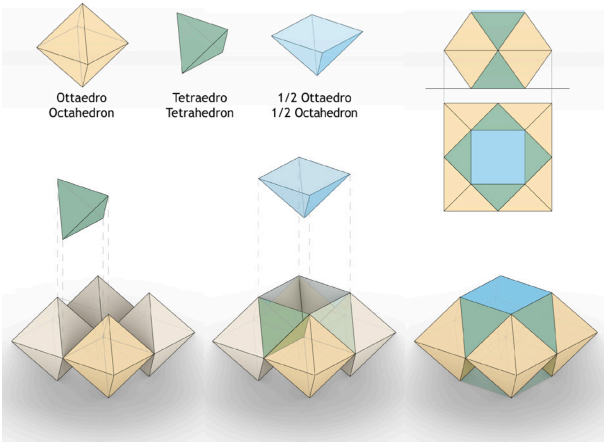


Fig. 2. Geometric definition of the "Octet parallelogram" (image by the authors).

and Buckminster Fuller [Edmondson 1986; Ulivieri 2025]. The building expresses a fundamental geometric principle: tessellation –the occupation of a plane through a figure that repeats without interruption. A notable example of this line of research is the Olivetti factory in Harrisburg, designed by Louis Kahn (1901-1974) in the '70s: a complete spatial tessellation generated by the planimetric intersection of two squares, producing an alternation of irregular octagons and squares. Particularly significant is the roof designed by Renzo Piano (1937), composed of an innovative system of square-based pyramids in fibreglass. Innovation and experimentation therefore represent essential elements of the time – and are equally central to Giorgini's vision. The geometric intuitions first explored in Tuscany gained new coherence in the United States, where the two-dimensional ideas of *Casa Esagono* evolved into fully three-dimensional systems. Giorgini developed interpenetrating volumetric configurations that define fluid, continuous spaces with spatial dynamism at their core. These outcomes derive from the use of regular Platonic solids, whose aggregation generates a spatial grid expandable in all directions [Del Francia 2000; Ulivieri et al. 2020; Moretti 1952]. These reflections position Giorgini within a broader technical and cultural context while emphasising his singularity. They provide the conceptual basis for the later maturation of his thought, fully expressed in his American projects.

Fig. 3. Spatial visions and formal relations between Giorgini's projects: from left to right: Genesis, Walking Tall, Hydropolis, linked by elevated paths (B.A.Co.-Vittorio Giorgini Archive: coll. PICT0140).

The american projects: geometry and structures as principle

"The concept of system and its structure serves as a tool to decipher the nature of phenomena. Given a certain criterion, we can recognise an element as part of an 'ensemble' and understand its relationship with the other parts. When, within a phenomenon, we are able to identify a set of elements, then we are recognising a system" [Giorgini 1995, p. 211].

Giorgini acknowledged the importance of defining distinct yet aggregable design components, governed by geometric principles able to adapt to different functions. Geometry is the true ordering element –from it derive both structure and function. Within this framework, the architect drew a distinction between 'Spatiology', the theoretical study of geometry as a mathematical discipline and foundation of statics, and 'Urbology', which translates such concepts into systems capable of interacting with the city rather than with the single building. The American projects

Walking Tall and *Hydropolis* exemplify this approach, as both engage with the urban and infrastructural scale. Although conceived for different functions and characterised by apparently contrasting formal languages, both projects reflect Giorgini's ethical and methodological coherence. They may be interpreted as multi-scalar systems comparable to Jan Lubicz-Nycz's (1925-2011) '*Urbatetture*', praised by Bruno Zevi (1918-2000) for their abandonment of rationalist stereotypes [Zevi 1965], or to the 'Megastructures' described by Reyner Banham (1922-1988) [Banham 1976]. Giorgini's focus is directed primarily towards urban space: interior layouts remain schematic, while the structural organism, drawn in detail, becomes the true protagonist. Both projects are set in New York, a city Giorgini interpreted as a laboratory for visionary experimentation. The metropolis embodied the ambition to "conquer the sky" through increasingly bold skyscrapers, yet *Walking Tall* was conceived as an antithesis to that model. Designed for a site between 49th and 50th street and between 8th and 9th avenue, the building rises approximately 250 metres high and, thanks to its geometric structure, combines rigidity with expressive lightness [Del Francia 2000, p. 77]. Its programme is highly innovative: a dynamic tower active 24 hours a day, with offices, residences, and studios in the central levels, and public spaces gathered within a tetrahedral crown at the top [Giorgini 1995, p. 240; Guerriero 2000, p. 77]. The tower does not occupy the whole plot: it stands on three tetrahedral steel supports, thus freeing the ground for public use. An elevated walkway, defined as *tetraprismic*, channels pedestrian flows, introducing a new three-dimensional layer of urban circulation.
Volumetrically, the building results from the interlocking of two bodies: a square-based pyramid and a triangular-based pyramid, as shown in the collage drawings in figure 1. The archival material reveals how the tower is organised through hierarchical 'ensembles' and 'sub-ensembles' that define the structural logic.
A crucial aspect concerns terminology: Giorgini rejected the reductive use of the word 'structure' as merely a static or constructive system, insisting instead on its primarily geometric nature, from which technical and functional solutions derive [Giorgini 1995, p. 211]. The tower therefore operates as a tensile structure, based on a primary system of beams and tension cables forming the external profile, and on a secondary internal support structure. The irregular triangular façade grid plays both an expressive and a structural role, likely exposing the load-bearing cables of the floors (fig. 1).

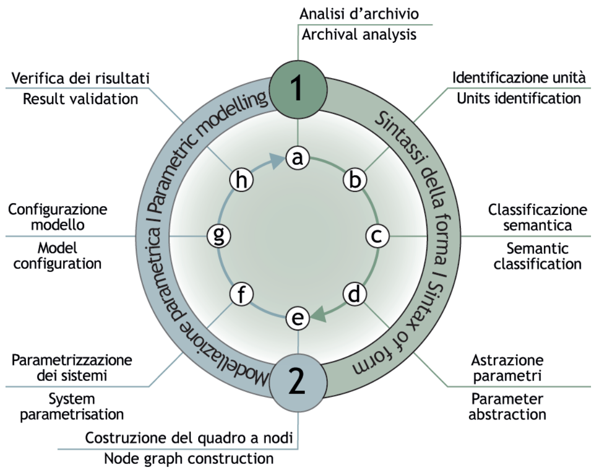


Fig. 4 Methodological Workflow (elaboration by the authors).

Despite its differences from earlier works, the project retains clear connections with Giorgini's previous research: the use of Platonic solids, the analogy with natural structural systems, and the absence of a 'main façade'. The building presents no privileged viewpoint, it changes radically depending on perspective, denying hierarchy and proposing an egalitarian spatial condition. Its generative logic also opens to possible aggregation with other architectures, suggesting an urban system rather than an isolated object.
If *Walking Tall* partially conceals its geometric logic beneath a tensile expression, *Hydropolis* makes it explicit. Here Giorgini adopts an analytical approach: he decomposes the project into parts and reassembles them into a coherent unit capable of operating across scales and addressing emerging socio-environmental issues. *Hydropolis* is the first stage of a genealogical sequence that later develops into *Genesis* (1984) and *River Crane* (1993).
The project occupies a portion of the East River waterfront, between 16th and 24th street, an area then subject to a competition for 1,786 dwellings, a 240-room hotel, restaurants, theatres, and leisure facilities [Giorgini 1995, p. 239; Guerriero 2000, pp. 77-83]. The analysis reveals a structural system based on aggregation logics derived from Platonic solids: the octahedron defines the main residential grid, while the tetrahedron regulates circulation

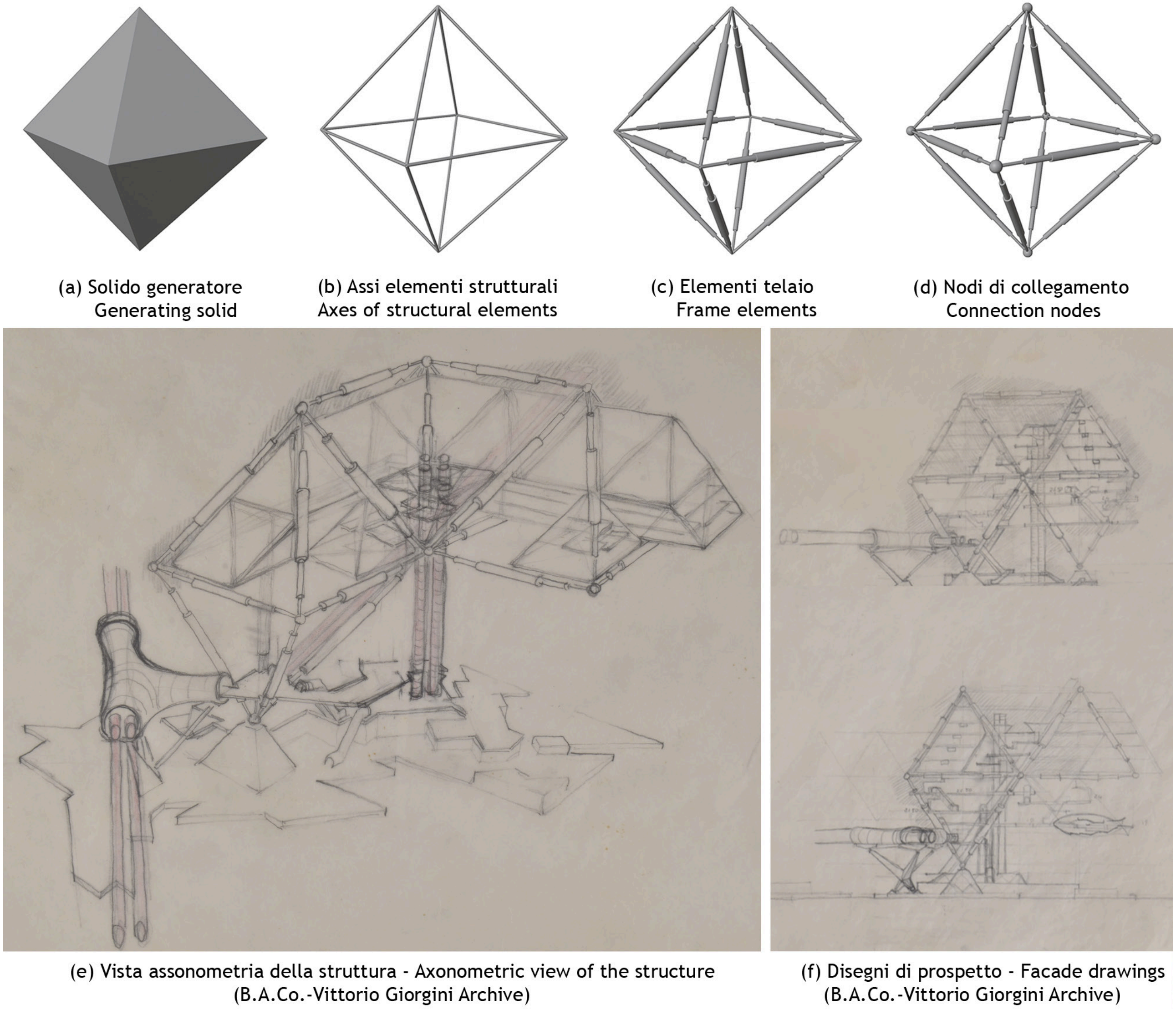


Fig. 5. Hydropolis: study and modelling of the base structural frame (image by the authors).

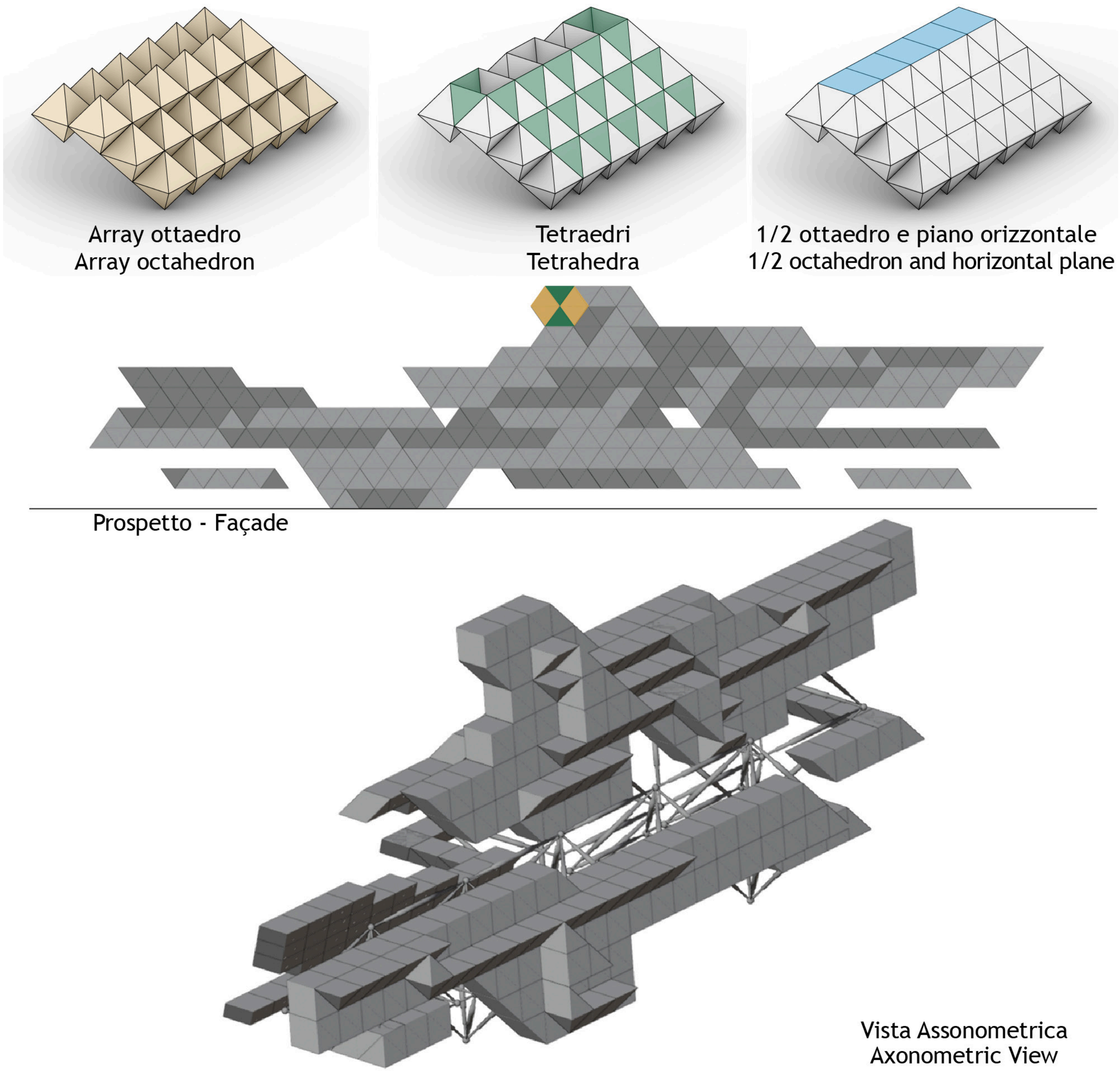


Fig. 6. Hydropolis: compositional logic of fundamental units (image by the authors).

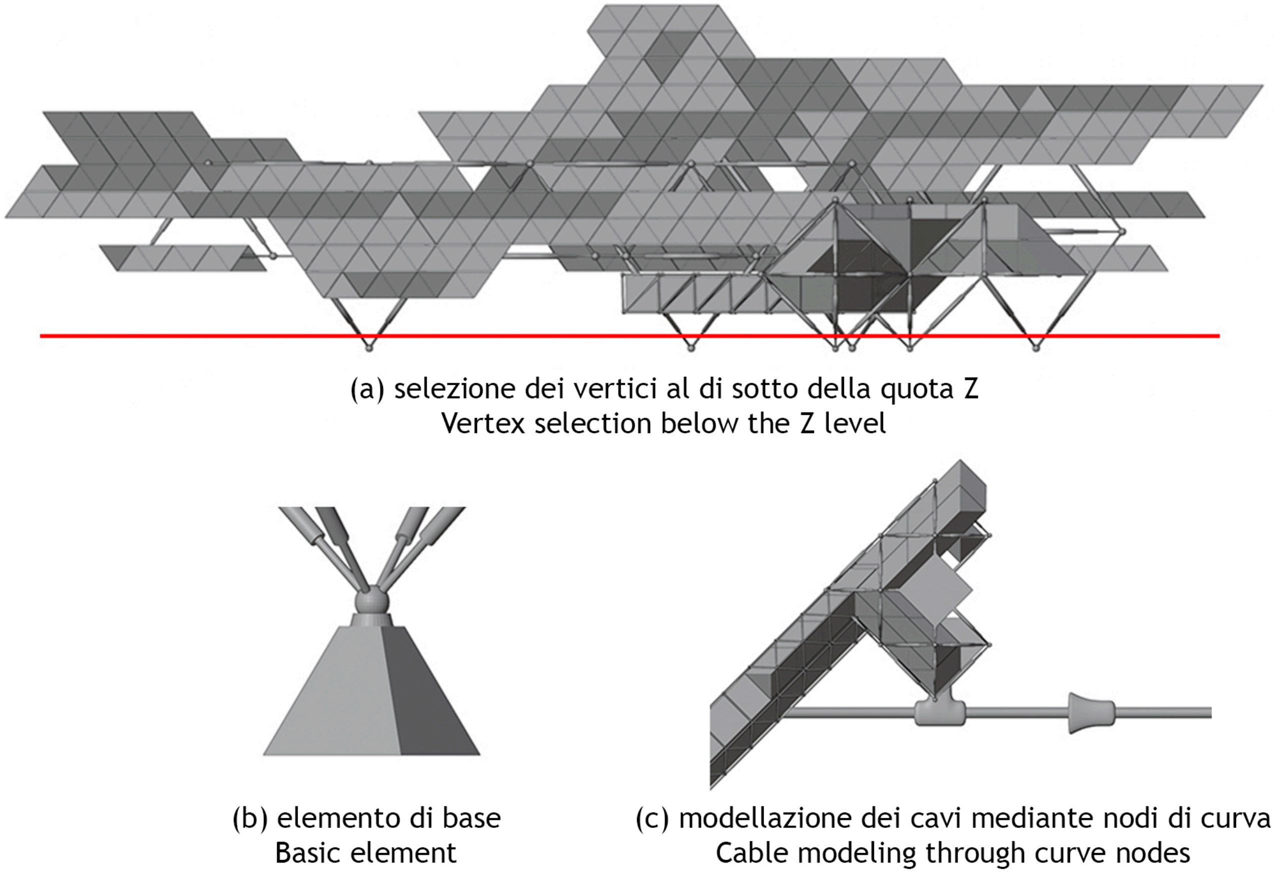


Fig. 7. Hydropolis: functional components (image by the authors).

and infrastructural connections. From a static viewpoint, these solids form a three-dimensional, self-supporting lattice able to withstand 'external forces' without bracing, while entirely occupying space. Their intrinsic stability ensures constructive autonomy, modular replicability, and economic viability.

The building can be divided into three main components: load-bearing trusses, responsible for the structural framework; the geometric grid, giving form to the inhabitable body; systems of connection, both internal and urban.

The main structure consists of telescopic tubular trusses –a continuation of the experimental work begun with *Walking Tall*– organised according to an octahedral lattice and integrated with the unit Giorgini called the "Octet parallelogram" (fig. 2) [Giorgini 1995, p. 244], composed of one tetrahedron and two half-octahedra, required to complete tessellation and define horizontal planes. Internal distribution follows a subtractive logic: the square modules obtained from horizontal sections of the octahedral grid are progressively modified to produce fluid

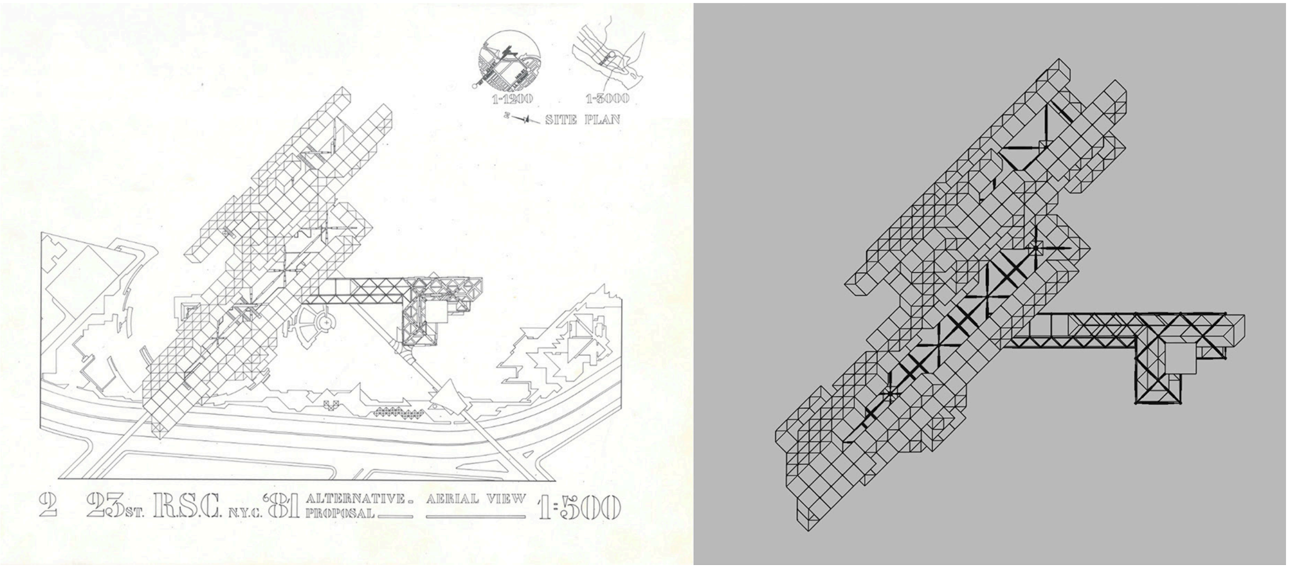


Fig. 8. Hydropolis: comparison between and original drawings (left) (B.A.Co.-Vittorio Giorgini Archive) and digital model (right) (image by the authors).

spatial sequences, double heights, and openings towards the exterior. Vertical connections are organised as a tubular system embedded within the frame, comparable to a biological organism, accompanied by an oblique emergent element, presumably with infrastructural and landmark functions.

Hydropolis reflects Giorgini's attention to the relationship between architecture and environment, proposing itself as an alternative to the winning entry of the competition: a solution that reinstates continuity with the river and enhances the natural setting. The project is conceived as an artificial suspended island connected to the city through lightweight infrastructures. Its intent is to avoid what the architect called the "pedestal effect" [Giorgini 1995, p. 226] –the monumental imposition of architecture upon the ground. Giorgini openly criticised such approaches, arguing instead for a balanced relationship among building, soil, and air, in line with Le Corbusier's principle of freeing the ground plane. However, a contradiction remains: while the project aspires to environmental integration, its serial vocation makes it theoretically replicable anywhere, thereby losing contextual specificity. In this sense, *Hydropolis* can be read as the first example of an aggregative system later reinterpreted in *Genesis* and *River Crane*. These projects demonstrate how the same conceptual nucleus –an abacus of modular geometric elements'– can generate multiple spatial configurations. The full meaning of *Hydropolis* thus emerges only when interpreted as part of a broader urban vision. In his proposals for New York, Giorgini did not seek to respond to punctual needs, but to outline a 'city of the future' capable of freeing the ground, inhabiting elevated spaces, and re-establishing a relationship between people, city, and nature. In this perspective, architecture becomes part of a complex, sustainable urban fabric –consistent with the principles of 'Urbology' [Giorgini 1982] (fig. 3).

Generative logics in the architecture of Vittorio Giorgini

The relationship between architecture and geometry is a central theme in Giorgini's work. His architectural forms derive from a combinatory process based on fundamental geometric units –an abstraction that takes material form through the dynamic control of compositional logic.

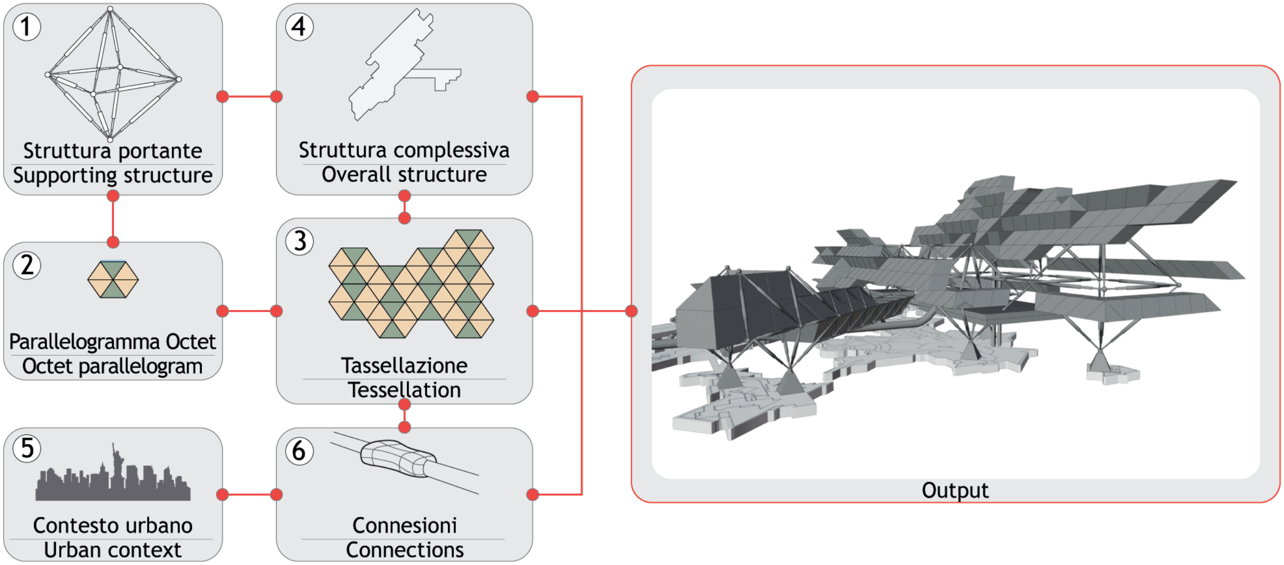


Fig. 9. Summary of parametric workflow applied to Hydropolis (image by the authors).

In this framework, procedural modelling tools based on visual programming (VPL) represent a particularly suitable instrument for analysing his architectural thought.
VPL software such as *Grasshopper* or *Blender Geometry Nodes* allows one to go beyond mere digital reconstruction and instead encode entire complex generative systems. These systems can be dynamically modified by acting on specific parameters. The approach makes it possible to identify and parametrise the fundamental geometric units of a project, while managing compositional logic flexibly in relation to context.
The study of *Hydropolis* and *Walking Tall* followed a two-stage methodology: 1) analysis of Giorgini's drawings and manuscripts to identify geometric units, methods of aggregation (overlapping, connection) and overall design logic; 2) VPL digital modelling using Blender's Geometry Nodes to translate the decoded logic into a node-based workflow (fig. 4). Compared to other software [5], *Blender* promotes the sharing and reproducibility of results, in line with Open Science principles. The adopted method allows not only the visualisation of fundamental units, but also the analysis of their compositional flexibility and the validation of their digital transposition in Giorgini's architectures.
Although *Hydropolis* and *Walking Tall* differ in geometric grammar, they share a systematic and procedural nature, which has enabled this method to be tested and validated. The modelling process for *Hydropolis* developed through four main steps, corresponding to the construction and validation of the parametric model:

1. Load-bearing trusses: modelling begins with a generating octahedron. Its edges are converted into variable-radius cylinders forming the structural frame. nodes such as *Instance on Points* and *Array* enable the positioning of connection elements (spheres) and the duplication of structures into linear sequences (fig. 5).
2. Generation of architectural form: the composition is based on the geometric structure of the "Octet parallelogram". By using array nodes, octahedra and tetrahedra are spatially arranged to create three-dimensional tessellation and define levels. Dynamic array control allows multiple volumetric configurations faithful to Giorgini's drawings (fig. 6).

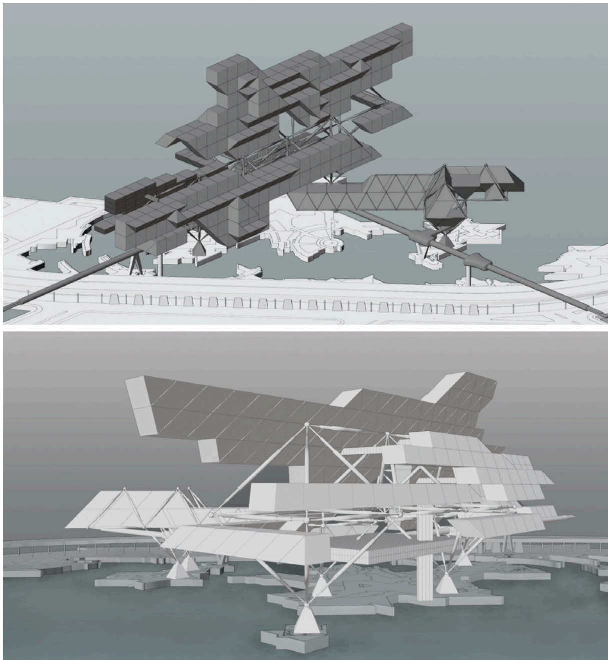


Fig. 10. Hydropolis: perspective digital views of the parametric model (image by the authors).

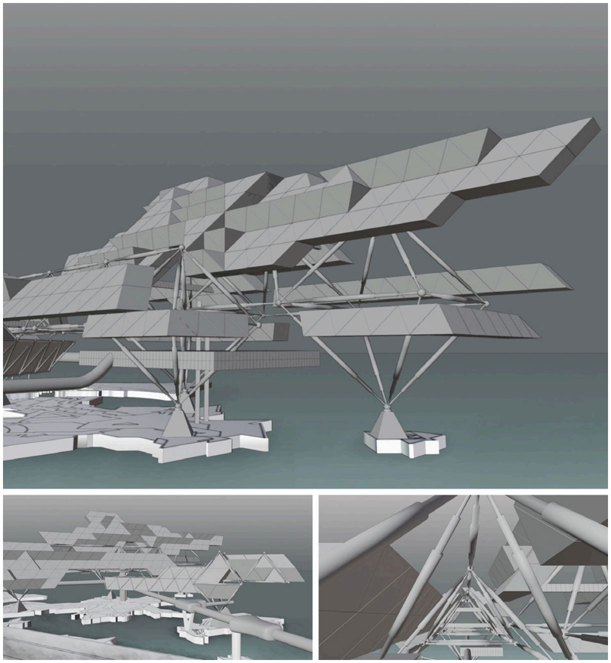
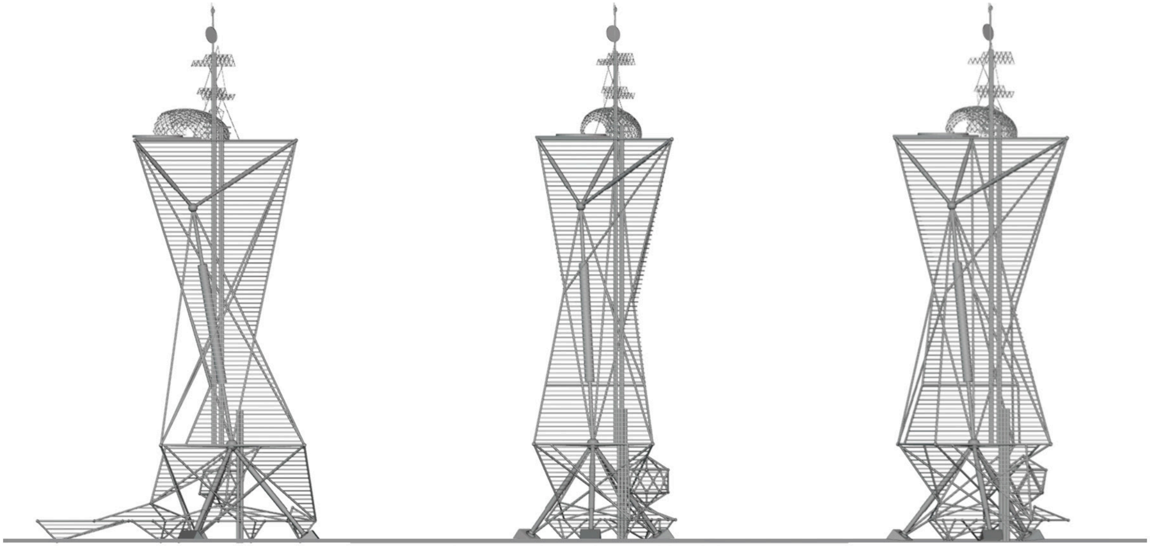


Fig. 11. Hydropolis: perspective digital views of the parametric model (image by the authors).

3. Ground connection and cable systems: missing architectural components, such as the connection between trusses and foundation plinths, were modelled using *Solidify* modifiers applied to parametric curves, then integrated into the node system to complete the model (fig. 7).
4. Model validation: the digital model was checked against archival drawings. The match in terms of geometry, proportions, and spatial organisation confirmed the validity of the parametric method, demonstrating how compositional units can be adapted to generate new forms (fig. 8).

The complexity of the node graph was managed through techniques such as *Node Groups*, *Frames*, and *Colour Coding*, facilitating development and maintenance (fig. 9).
The same generative framework can be extended to later projects such as *Genesis* and *River Crane,* which share identical compositional principles (figs. 10, 11).

Unlike *Hydropolis*, *Walking Tall* is based on the combination of inverted square- and triangular-based pyramids forming the structural skeleton. Once again, Giorgini's logic is grounded in geometric lattices and intersection nodes. The floor slabs were modelled as an array of parallelepipeds, while elementary volumes were used to define building boundaries through Boolean operations. The VPL modelling required a separate node graph, demonstrating the method's ability to adapt to different geometric grammars, faithfully reflecting Giorgini's exploratory approach (figs. 12, 13).
The VPL modelling of both case studies validated the coherence of Giorgini's geometric grammar and its effective translatability into operative parametric models. These models thus become dynamic tools for interpreting, visualising, and manipulating the architect's design logic, opening the way to further research and applications.



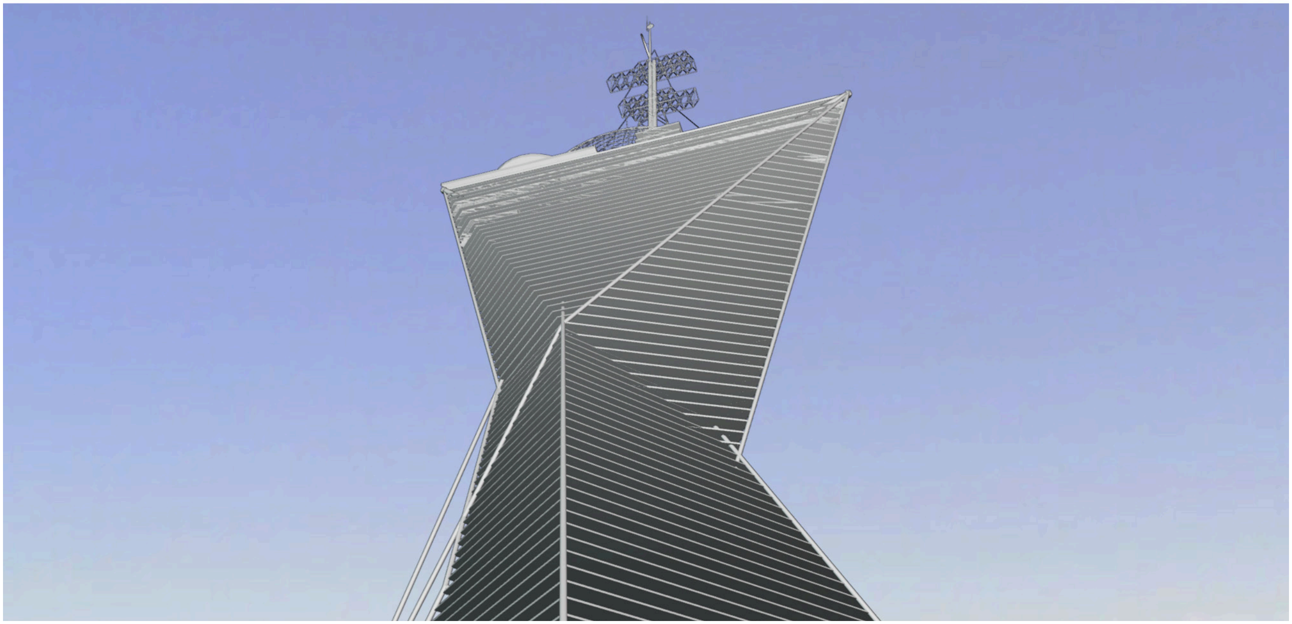


Fig. 12. Virtual modelling of Walking Tall: frontal and top views (image by the authors).

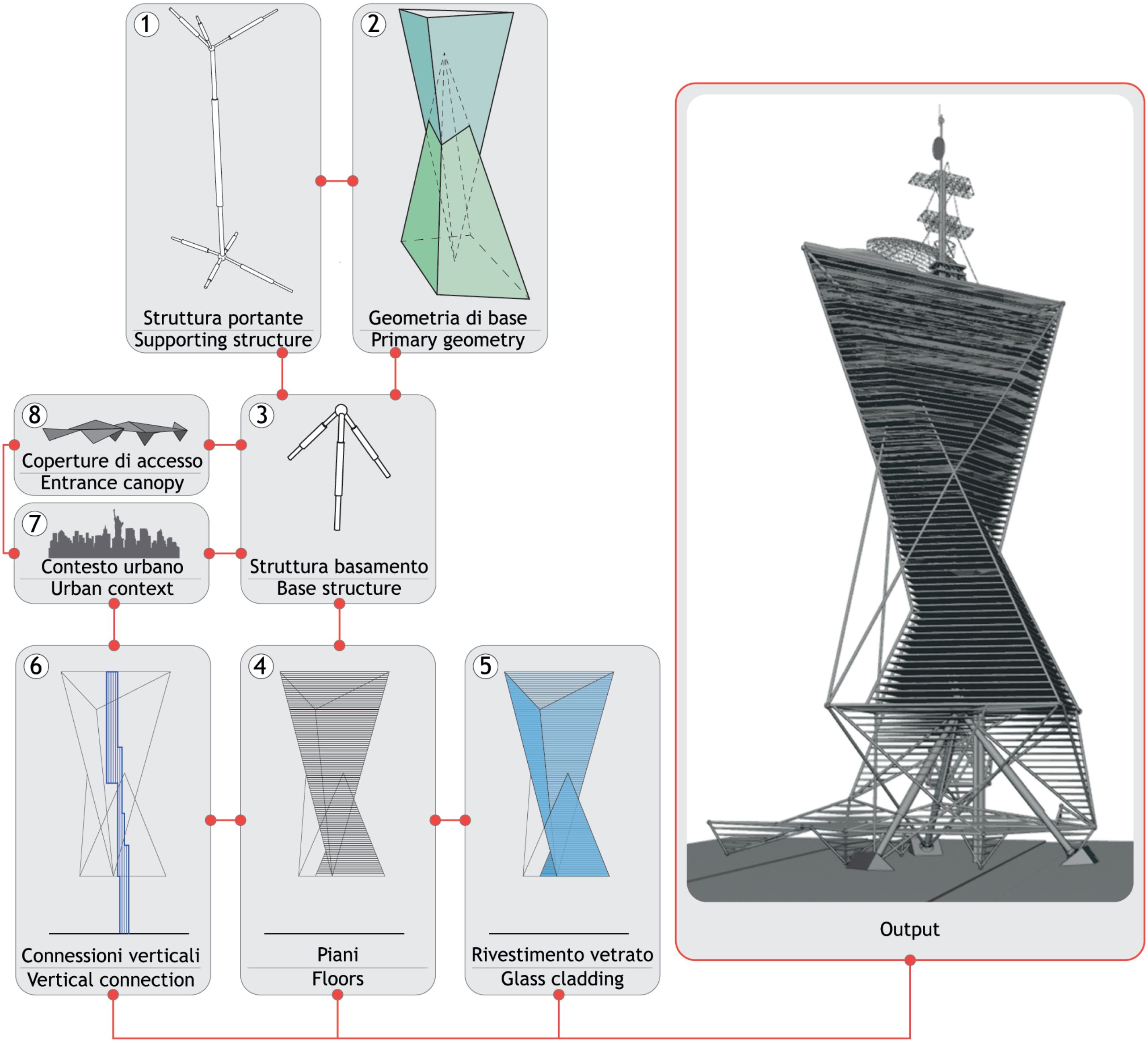


Fig. 13. Summary of parametric workflow applied to Walking Tall (image by the authors).

Conclusions

The analysis of Giorgini's American architectures restores to late twentieth-century historiography a figure of undeniable importance, capable of formulating innovative visions. *Walking Tall* and *Hydropolis* reveal a constant pursuit of an architectural language in which geometry operates as the primary generative and ordering principle, anticipating design methodologies legitimised only decades later by digital tools. His theoretical approach, translated into design terms, shows a clear intention to transcend the limits of the individual building and engage with complex, open, modular, and replicable urban systems. In this sense, Giorgini's research assumes not only experimental, but also ethical and political value: it proposes alternative models of the city able to reconcile urban growth, sustainability, and new relationships between person and environment. The digital translation made possible by VPL tools not only reconstructs unbuilt projects, but also verifies their feasibility, transforming reconstruction into a true testing platform. The shift from 'form' to 'parameter' allows us to grasp the generative logic underlying Giorgini's work, confirming its relevance and its ability to dialogue with contemporary design paradigms. Back in the 1980s Giorgini, already perceiving the creative potential of digital languages, was in contact with MIT, and began experimenting with early CAD software at Pratt Institute [Ulivieri 2025]. Today, in comparison to the tools available to Giorgini, we are able to model not only architectural forms, but the generative logics behind them. A deeper analysis of Giorgini's design genealogy, also through digital methods, could clarify the actual feasibility of his proposals. This is essential in order to distinguish his work from the purely utopian scenarios of his time: Giorgini considered his structures buildable, suitable for serial and mechanised production, and thus economically and constructively viable. Some limits remain, due to the fragmentary nature of sources and the interpretive effort required by complex digital models. Yet this can be read positively: as an invitation to consider the study of Giorgini as an open process capable of producing new hypotheses and variants, exactly like the architectures he imagined. The present contribution highlights the need to rediscover and re-evaluate a designer who, through a multidisciplinary and anticipatory vision, laid the foundations of parametric architecture ante litteram. His American projects are not only an unexplored chapter of architectural history but also provide critical and methodological tools for addressing contemporary design challenges, suggesting future scenarios in which geometry, technology, and utopian vision remain engines of innovation.

Acknowledgements

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Although the text was conceived jointly by the authors, Marco Giorgio Bevilacqua wrote the *Introduction* and *Conclusion* paragraphs; Denise Ulivieri wrote *Giorgini: the Florentine Architect in New York* paragraph; Piergiuseppe Rechichi and Zhangliang Shuai wrote *Generative Logics in the Architecture of Vittorio Giorgini* paragraph; Alessandro Meloni wrote *Visionary Structures: Space, Geometry, Architecture* and *The American Projects: Geometry* and *Structures as Principle* paragraphs.

Notes

[1] See: Castellano (1987a-b); Del Francia (2000); Ulivieri *et al.* (2020); Ulivieri *et al.* 2022a; Ulivieri, Bevilacqua, Iardella (2022b); Ulivieri (2025).

[2] B.A.Co.-Vittorio Giorgini Archive - Follonica (GR), Italy; Centre Pompidou; FRAC Centre-Val De Loire.

[3] See: Del Francia (2000; 2006; 2011); Ulivieri *et al.* (2020); Ulivieri *et al.* (2022); Del Francia, Ulivieri (2024).

[4] On Giorgini's stay in New York (1969-1996) and his U.S. connections: Ulivieri (2025).

[5] In addition to the software mentioned, examples include: *Grasshopper* and *Dynamo.*

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RUBRICS

Readings/Rereadings

Readings/Rereadings

The Representation of Constructive Forms

Federico Fallavollita

Introduction

The volume *La représentation des structures constructives* by Adrian Gheorghiu and Virgil Dragomir [Gheorghiu, Dragomir 1968], the former an architect and the latter an engineer, was published in France in 1968 as a translation of a previous Romanian edition (fig. 1) [1]. It is a book that I regard as a working companion and, in a certain sense, a pivotal reference in my own education: for nearly twenty years it has accompanied my research, ever since I first studied it during my doctoral work at Sapienza University of Rome, where it served as an indispensable text for understanding the geometric nature of ruled surfaces. Over the years, I have come to appreciate that this work is not merely a technical manual; it is, rather, a true treatise on the profound relationship between form, structure, and representation, capable of speaking even today to architects, engineers, and scholars concerned with the logic of spatial configuration.

The book is organized into three principal sections. The first, *Perspective Drawing, Structural Statics and the Aesthetics* [2], is a lengthy conceptual and technical introduction devoted to the role of drawing, particularly axonometric representation, as an instrument of thought and as a method for analyzing architectural forms. The second, *From Geometric Surfaces to Thin Curved Shells*, offers an extensive treatment of curved surfaces, interpreted not merely as geometric objects but as genuine constructive devices. Each type of surface is presented in relation to historical and contemporary examples, producing a sort of visual atlas of curved structures. The third part, *From Polyhedra to Space Frames*, focuses on polyhedral geometries and spatial reticular structures, demonstrating how a deep understanding of polyhedra remains indispensable today for complex three-dimensional systems ranging from geodesic domes to large lightweight coverings. Notably, this section includes a chapter entitled *Framed Structures*, which anticipates developments in mesh geometry and, to a certain extent, in the geometry of folded surfaces associated with origami mathematics [Pottmann et al. 2007], a field that has experienced significant growth in recent years, partly owing to the digital revolution.

From the opening pages, the authors clarify the aim of the work: to present in a systematic way the geometric principles underlying the most recent architectural structures

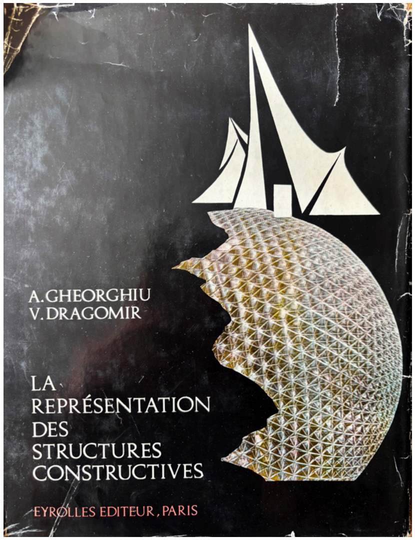

Fig. 1. Cover of the first French edition of the book [Gheorghiu, Dragomir 1968].

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of the 1960s, and to demonstrate how axonometric drawing constitutes the most suitable language for understanding, managing, and representing them. This aim is not secondary; it reflects a specific epistemological stance whereby geometry is not a language superimposed upon architecture, but a cognitive system that precedes and informs the design process itself.

The gap between technical manuals and the design process

One of the authors' most prescient observations concerns the fragmentation of technical manuals. Most specialist texts, Gheorghiu and Dragomir note, present only the outcome of a project: photographs, simplified elevations, partial construction diagrams. What is missing is the continuity of the logical process: data selection, geometric decisions, and the genesis of form. In other words, what is absent is the 'thinking' that mediates between problem and solution. For this reason, the book does not aim to present only geometric results; it seeks instead to reconstruct the methodological path that links perception, representation, verification, and construction.

A second shortcoming, more conceptual in nature, further complicates this situation: the geometry of representations has not kept pace with developments in structural statics. While computational methods have become increasingly sophisticated, the geometric component often remains tied to traditional forms, unable to accompany technical imagination toward new spatial solutions. The result is a growing disconnect between what can be calculated and what can be imagined and represented. Geometry, by contrast, ought to serve as a bridge: a shared language enabling architects and engineers to communicate visions and methods.

The role of parallel perspective or axonometry

The first part of the book offers an in-depth review of techniques of parallel perspective drawing, understood not as a mere representational method but as a genuine tool for discovering form. For Gheorghiu and Dragomir, parallel perspective, unlike orthographic double projections, enables a closer relationship between image and space: it preserves parallelisms, proportional relationships, and linearity while providing an immediate and, crucially, manipulable reading of volume.

For this reason, axonometry becomes the central language of the volume. The Pohlke-Schwarz theorem, which guarantees the possibility of representing any three-dimensional system through a single two-dimensional image, serves as the theoretical basis for constructing a geometry of structures that is both rigorous and intuitive. In axonometry, one may directly take measurements from the drawing, assemble and decompose forms, and assess the coherence of a structure. In this sense, axonometric drawing functions not merely as a representational device but as a 'thinking machine'.

Structure, form, and image

The theme of interdependence between form and structure is approached through a critical re-examination of the tradition of stereotomy. While in the past the form of masonry vaults resulted from a complex balance between geometry and technique, the advent of new materials, steel, reinforced concrete, membranes, prefabricated components, has radically altered those logics. Yet, the authors argue, the fundamental principle remains unchanged: structure must be conceived as a coherent system of lines, surfaces, and volumes, and the spatial image that emerges must express a synthesis of function, technique, and form.

Image is not ornament, nor a mere visual effect: it is the manifestation of constructive order. A building 'expresses' itself through its image, which conveys the internal logic of the structure to the observer. It is therefore essential that geometry be fully aware of structural requirements: a form lacking constructive logic produces a misleading image, whereas a form generated by a coherent structural system yields an image that is clear, historically grounded, and culturally meaningful.

The authors emphasize the role of intuition in the genesis of any project. They cite a well-known reflection by Pier Luigi Nervi, who observed that ancient builders were able to conceive extraordinary works without modern computational tools because they possessed a profound intuition of form and forces. For Nervi, as for the authors of the book, calculation cannot replace intuition, which instead emerges from geometric understanding and constructive experience.

The preliminary image of the structure, the one that arises prior to calculation, is, for Gheorghiu and Dragomir, the heart of the design process. This image must be both evocative and rigorous, capable of evolving through two series of approximations: one linked to statics, the other to representation. Neither can progress independently: form cannot be defined without considering forces, and statics cannot be understood without a form that represents it correctly.

'Descriptive Geometry'
and axonometry compared

The book devotes a considerable attention to the relationship between image, projection, and drawing. The three-dimensional image constitutes a complex synthesis of visual, tactile, and motor perceptions; technical drawing, however, must reduce this complexity to a construction governed by geometric principles. Conical and cylindrical projections define fundamental relationships between planes, congruence, homothety, affinity, and projectivity. These are not mere theoretical abstractions but operational tools through which space can be transformed, analyzed, and represented.

The authors do not deny the importance of double orthogonal projections for the study of form; however, they note that perceptual intuition relies on a more immediate spatial image, rendered effectively by axonometry. Both methods share a crucial feature: they produce reciprocal representations, allowing one to reconstruct space from the image and, conversely, to intervene in the image as though operating directly in three-dimensional space.

The comparison between Descriptive Geometry (understood by the authors as double orthogonal projection) and axonometry is developed with clarity. Monge's double projection requires complex notation and does not allow an immediate reading

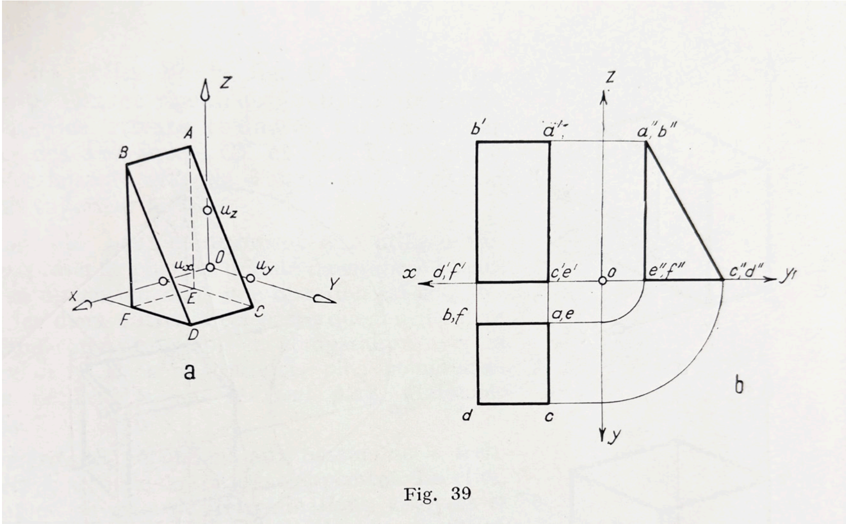


Fig. 2. Comparison between the drawing in 'Descriptive Geometry' and oblique axonometry [Gheorghiu, Dragomir 1968, fig. 39, p. 41].

of volume. Axonometry, by contrast, provides a single synthetic image that preserves parallelisms and proportions and allows the use of three independent scales along the axes. For this reason, the authors regard parallel perspective as an instrument more closely aligned with design logic and more useful for describing complex structures such as latticed or surface-based systems (fig. 2).

A particularly interesting observation concerns the choice of axes and unit scales: the authors demonstrate how an ill-considered choice can distort the image to the point of rendering it unusable, whereas a well-considered choice, often guided by the construction of a 'reference cube', produces a balanced, legible image. This attention to graphic detail confirms that the geometry of representations is not merely a technical discipline but a genuine art of perception.

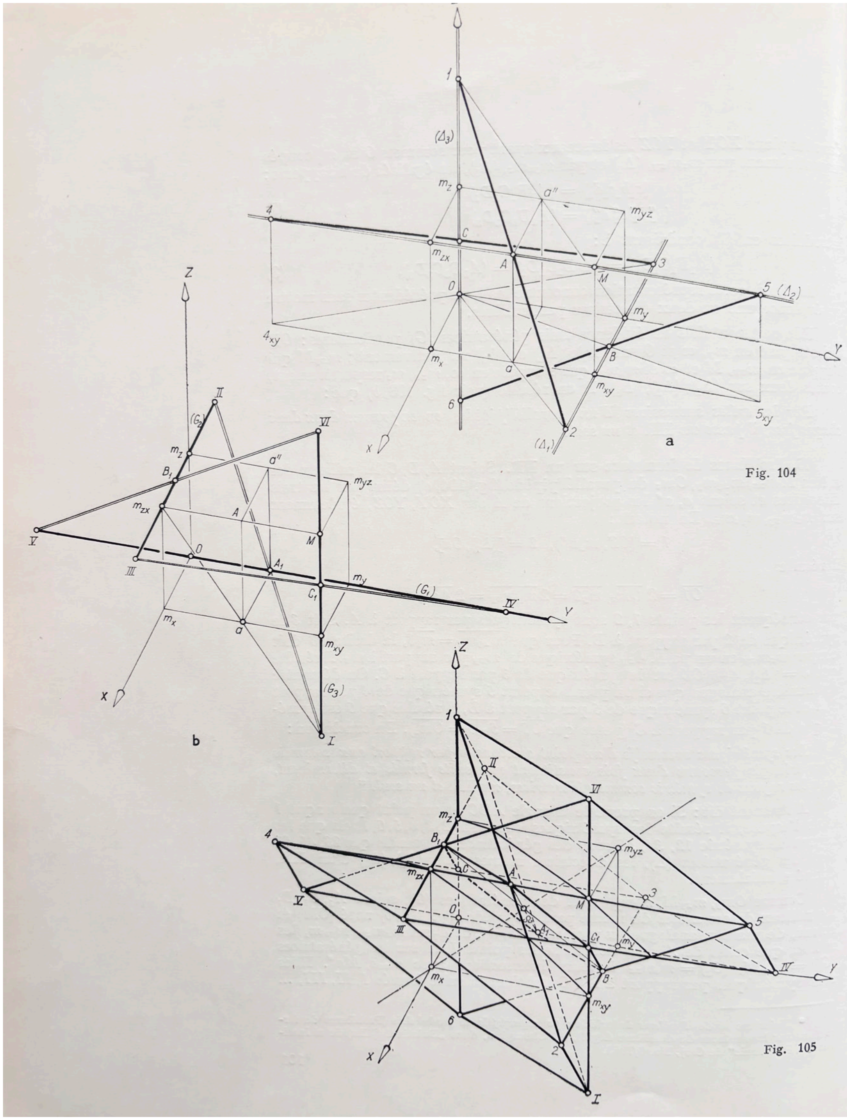
Another remark on axonometry, especially noteworthy, deserves to be quoted: "The spatial image does not correspond to human vision (at finite distance), as in conical perspective, but it is sufficiently good, especially for small objects, or for very large objects viewed from a great distance (as a whole)" (p. 42). The implicit comparison with perspective and visual perception opens a wide field of reflection; it is enough to note, however, that the authors are fully aware of two fundamental modes of representing the world: as it looks and as it is [Arnheim 2009]. Axonometry emerges, in their interpretation, as an intermediate solution, capable of describing the objective structure of forms without straying too far from their perceptual appearance.

A personal example: the constructive parallelepiped

Among the many insights and indications contained in the book, one has been particularly decisive for me: the construction of what I call the 'constructive parallelepiped' [3], described in the section *Problèmes de fermeture sur un HR* (fig. 3). During my doctoral research, I was studying the exact generation of a ruled hyperboloid defined by three skew lines [Fallavollita 2008] [4]. Techniques based on interpolating generatrixes proved insufficient for constructing the surface in a complete and accurate way: they produced approximated surfaces, not rigorously quadratic ones [5]. I had come to understand, partly thanks to reading David Hilbert and Stefan Cohn-Vossen's *Intuitive Geometry* [Hilbert, Cohn-Vossen 1960], that an elliptic hyperboloid may be obtained by deforming a hyperboloid of revolution through an affine transformation. But to apply this idea, it was essential to determine precisely the centre of a general hyperboloid.

The construction provided by Gheorghiu and Dragomir offers exactly this: a rigorous geometric method based on constructing a parallelepiped associated with the directrices, which makes it possible to locate the centre of the surface and thus to generate the hyperboloid exactly. Though conceptually simple, it is highly effective and decisively shaped my understanding of the geometric genesis of the elliptic hyperboloid as a quadratic ruled surface resting upon three given skew lines (fig. 4). The procedure itself is extremely simple: it consists in determining the parallel

Fig. 3. The construction of the 'constructing parallelepiped' [Gheorghiu, Dragomir 1968, fig.105, p. 102].



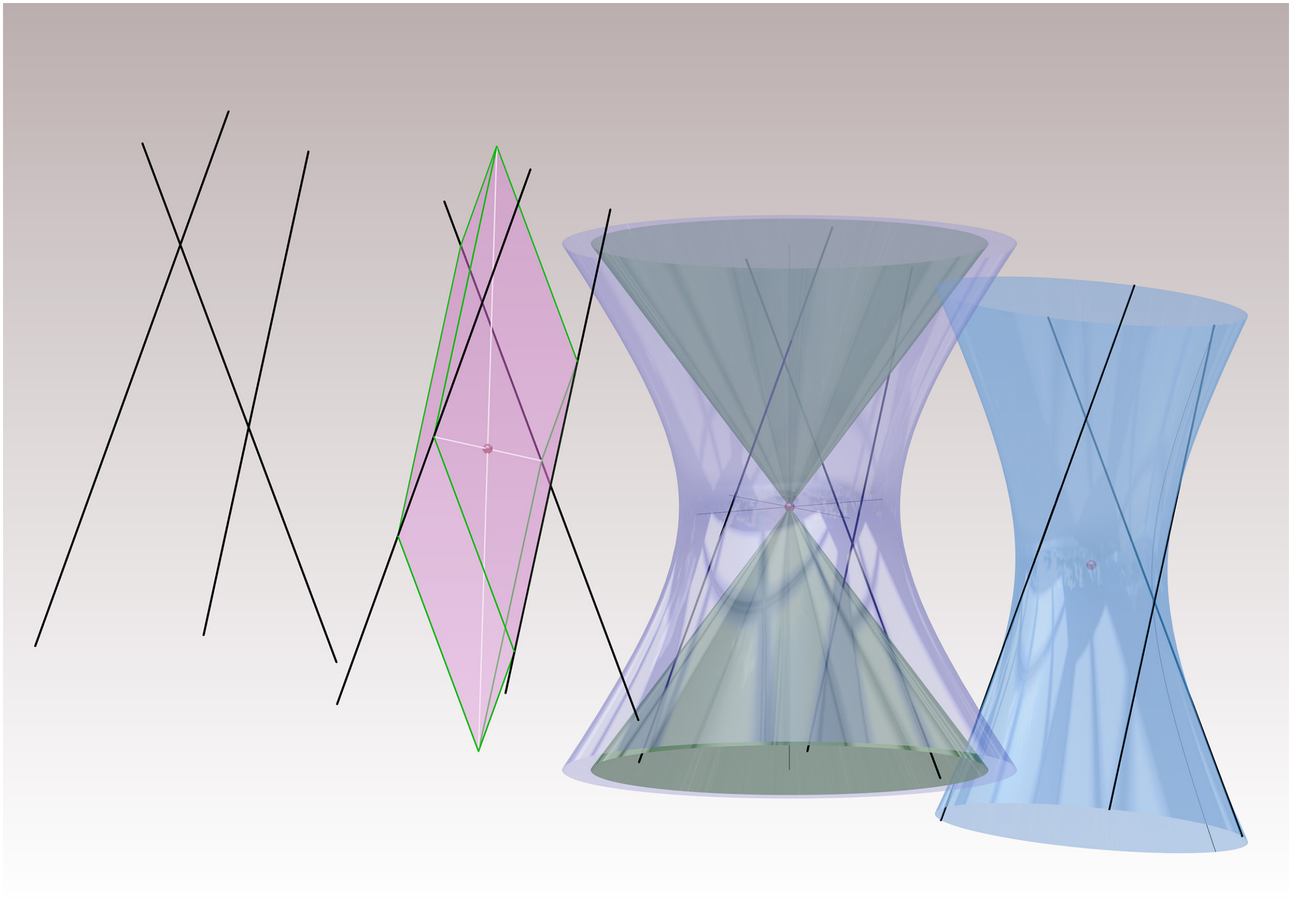


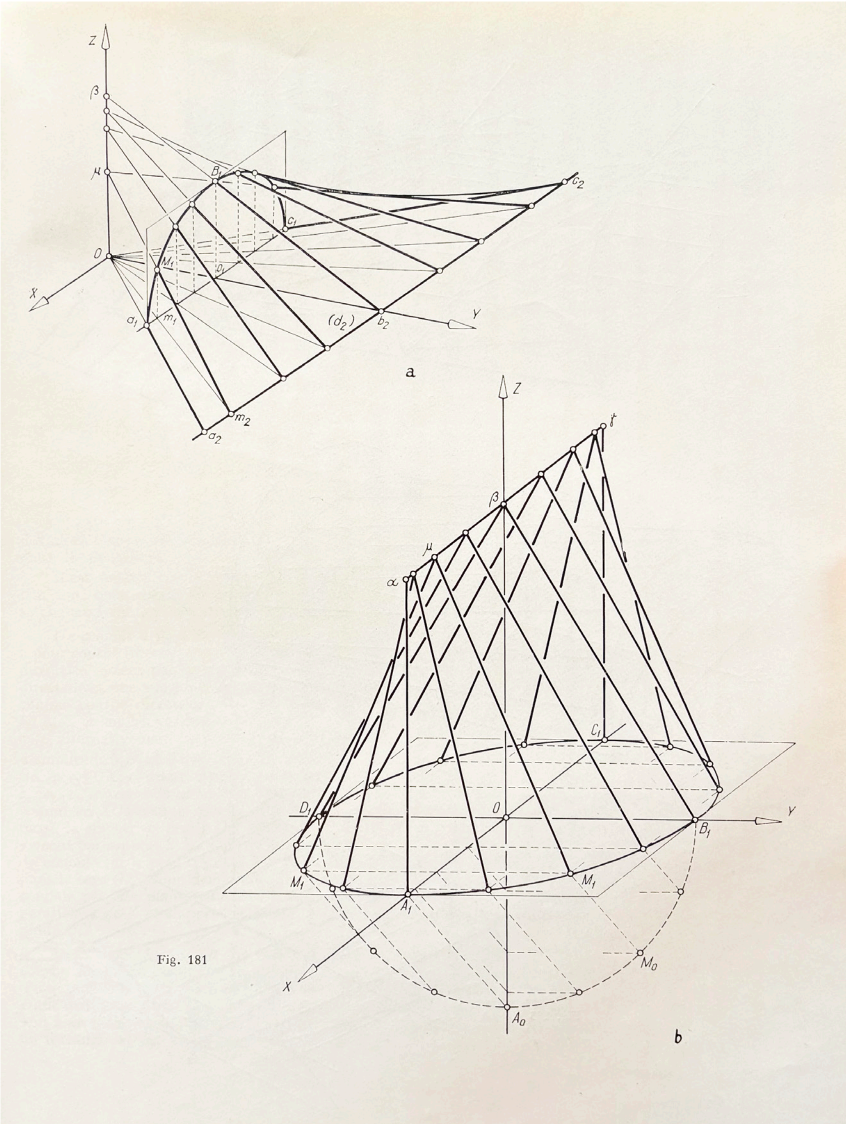
Fig. 4. The construction of the elliptic hyperboloid from three skew lines (graphic elaboration by the author).

planes passing through each of the three skew lines. These planes are obtained by constructing them in pairs. First, one superimposes the first line on the second and determines the plane passing through both; then one transfers this plane onto the first line to obtain the parallel plane through it. Repeating this operation for each pair of lines yields six planes in total: three pairs of parallel planes defining the constructive parallelepiped.

Conclusions

In the concluding section, the authors present the geometry of structures as a central discipline, capable of guiding design imagination far beyond what calculation alone may verify. Geometry is not an auxiliary language nor a mere technical instrument: it is the foundation through which form may be understood and controlled, its structural behaviour anticipated, and its aesthetic meaning assessed.

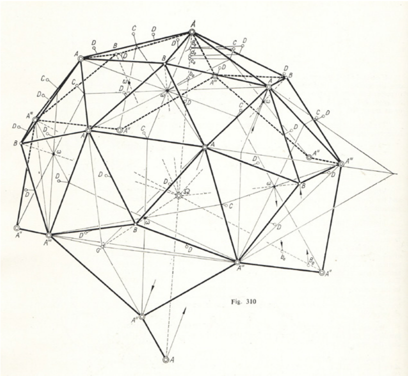
Fig. 5. The conoids [Gheorghiu, Dragomir 1968, fig.181, p. 167].

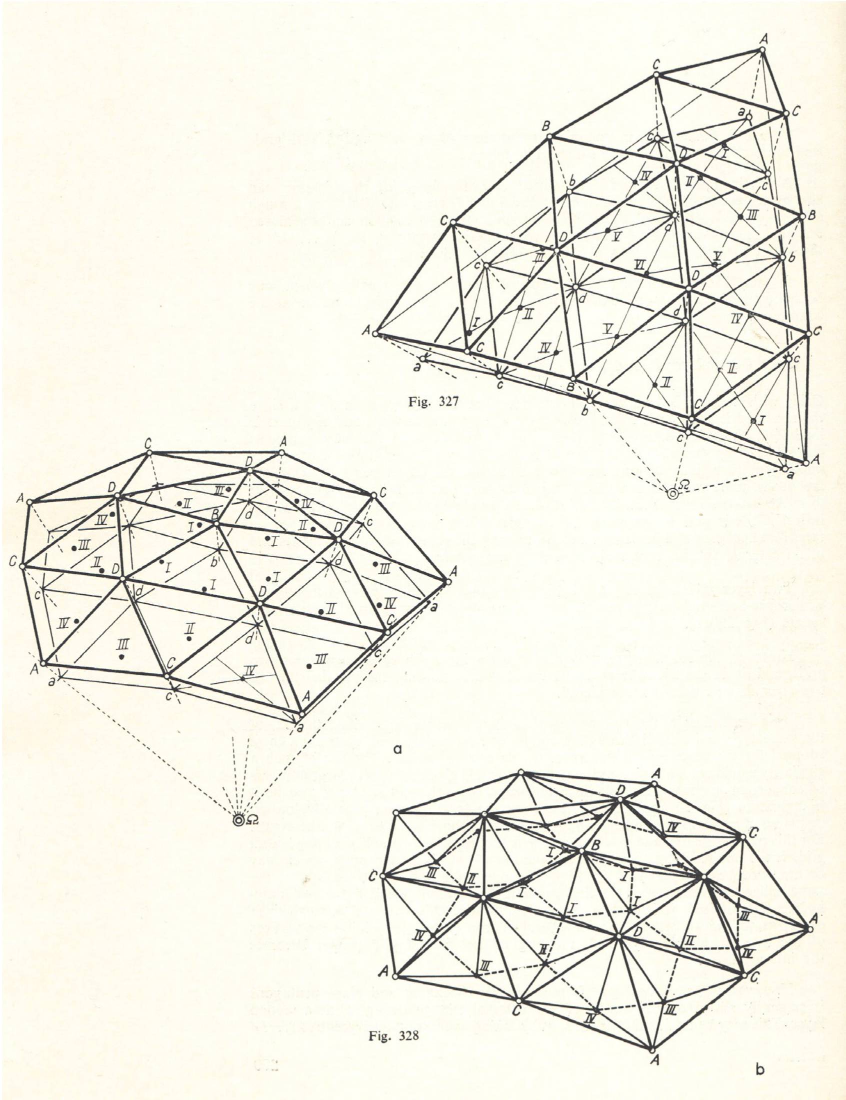


The new possibilities offered by computational methods greatly broaden the spectrum of realizable forms; yet such forms, to be persuasive and correct, must be rooted in a solid geometric understanding. In this respect, the authors argue, the Geometry of structures must develop the algorithms that will enable computers to assist, rather than replace, creative imagination.
The book thus situates itself within a broader theme: the Geometry of forms, structures, and representations in contemporary architecture and engineering.
More than fifty years after its publication, it remains remarkably relevant: it offers a method, a language, and a vision capable of addressing the complexity of contemporary forms without abandoning the theoretical robustness characteristic of the great European geometric tradition.
My final remark concerns the value of the geometric constructions and the related drawings (figs. 5-7). The work was conceived and written shortly before the digital revolution that transformed graphic representation. Yet the quality of the images does not suffer in the least: geometric forms are rendered with great clarity, enabling an impeccable reading of three-dimensional configurations.
This result is achieved with extremely simple graphic means: only two-line weights, a thin one for constructions and a thicker one for the final result, that is, for the forms depicted. The viewpoints chosen are always optimal and functional to the procedures described. No graphic embellishment, and yet the effectiveness is remarkable.

Fig. 6. Dodecahedral grids [Gheorghiu, Dragomir 1968, fig. 310, p. 266].

Fig. 7. Double-layer framed grids [Gheorghiu, Dragomir 1978, figs. 327 and 328, p. 287].





As for the constructions themselves, at first glance one might assume that they are now 'obsolete' or 'superfluous', since today it is possible to operate directly in three-dimensional space. This judgement, however, would be unfounded. Most of the procedures proposed in the text correspond to operations that, even in contemporary digital environments, are applied directly to spatial forms. Axonometry is employed as a tool for investigating geometric configurations in an immediate and spatial manner. Very few constructions are rendered unnecessary by digital modeling.
The constructions presented thus remain fully relevant and constitute an effective aid for understanding, generating, and analyzing surfaces and polyhedra, both in their abstract dimension and in their architectural applications.

Notes

[1] The first edition of the volume was published in Bucharest in Romanian-language under the title *Probleme de reprezentare a structurilor constructive* [Gheorghiu, Dragomir1968]; an English edition of the work also exists, published in 1978 under the title Geometry of Structural Forms [Gheorghiu, Dragomir 1978].

[2] The translation of the text from French into English is by the author.

[3] In the book this construction is presented under a different formulation. The theorem in question is set out on p. 101, in the section entitled *Problèmes de fermeture sur un HR*, and states: "The successive reflections of any point in space with respect to a triangle traversed twice constitute a closed and well-defined form, in which the axes of symmetry are the generatrices of a single one-sheeted ruled hyperboloid.": Gheorghiu, Dragomir 1968, p. 101.

[4] The construction of the hyperboloid through three skew lines was also published in the Migliari 2009, Sect. 2.3.4, *The One-Sheeted Hyperboloid*.

[5] The issue lies in the fact that, within the current NURBS-based mathematical representation, no automatic function exists for generating a ruled surface defined by three given directrices. The surface can only be produced in an approximate form by interpolating the three prescribed lines; however, the resulting model is neither rigorous nor fully accurate.

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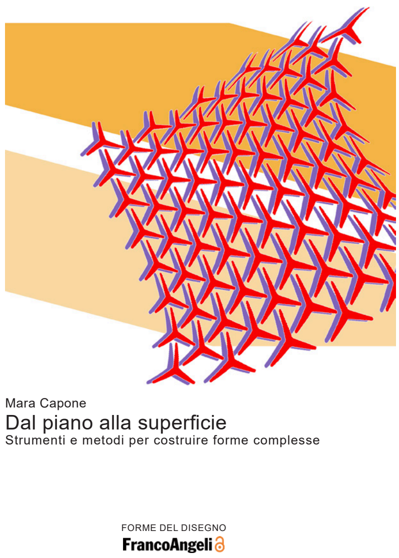
Reviews

Reviews

Mara Capone

Dal piano alla superficie. Strumenti e metodi per costruire forme complesse
FrancoAngeli
Milano 2024
218 pp.
ISBN 9788835166993



The book *Dal piano alla superficie. strumenti e metodi per costruire forme complesse* by Mara Capone presents itself as an articulated, in-depth work capable of tracing a coherent trajectory that connects the conception, representation, and transformation of geometric forms. The volume systematically addresses the different levels of complexity inherent to the subject, both from a theoretical and an operational perspective, also making use of the most advanced digital techniques currently available in the field of geometric modelling and parametric design. Its overall goal is to show how an understanding of geometric rules can serve as an essential foundation not only for grasping three-dimensional forms, but also for their conscious generation and practical production.

Within the discussion, Descriptive Geometry plays a primary role: it provides the conceptual basis for investigating three-dimensional shapes, understanding their internal logic, and analysing the processes that generate them from the bidimensionality of flat surfaces. In *Chapter 1*, for example, a significant portion of the text is devoted to classifying surfaces according to their geometric origin –surfaces of revolution, translation surfaces, helicoidal surfaces, ruled surfaces, interpolated surfaces– a categorization that is fundamental for anyone wishing to approach the generation of forms methodically, including by parametric tools.

A distinctive feature of the volume is the presence of frequent and well-targeted references to the historical origins of the scientific topics discussed. These are not simple digressions, but true interpretative tools through which the author highlights the variety of perspectives that have shaped the debate on geometric representation over time. This is the case, for example, with the introduction of the concept of differential classification of surfaces (*Chapter 2*), introduced by Leonhard Euler, taken up by Gaspard Monge, and later systematized by Carl Friedrich Gauss in 1902. The reference to Gaussian curvature thus becomes an opportunity to underline the close relationship between pure Geometry and Descriptive geometry, showing how a mathematical concept can become an operational tool for distinguishing, understanding, and representing surfaces with specific characteristics, such as developable surfaces. Developable surfaces, characterized by zero Gaussian curvature, receive particular attention in *Chapter 3*, where various methods for their construction and manipulation in virtual environments are illustrated. The discussion introduces a classification of developable

surfaces divided into conic, cylindrical and tangential ones. The latter hold a particularly significant place: they can be generated through geometric locus curves, intersection curves, or graphic lines, and the text carefully addresses each of these methodologies in a distinct and accurate manner.
The book includes numerous elaborations developed through VPL (Visual Programming Language) procedures. The use of visual language makes it possible to clearly express the logical steps that guide form construction, highlighting components, relationships, and control parameters. The choice of VPL also helps readers less experienced in traditional coding to approach complex processes such as parametric generation and subsequent surface transformation.
Chapter 4 illustrates in detail the methods for flattening developable surfaces, implemented through specific scripts applied to particularly significant case studies, such as the developable helicoid. The section opens with a solid theoretical overview enriched by historical references that help clarify the motivations and evolution of the problem. It then shows the construction of the helicoid in a VPL environment and introduces the developable script, an advanced tool capable of addressing the complex problem of unfolding a generic tangential surface –an operation that is not always achievable with the standard functions of some of the most common modeling software.
The volume does not overlook the topic of non-developable surfaces, which cannot be flattened onto a plane without tearing or overlapping. In this regard, techniques for converting digital models into physically producible elements are illustrated. Paneling, for example, makes it possible to build even double-curved surfaces by discretizing them into rigid, non-deformable panels capable of assembling into multiple configurations. Alongside this is discretization into strips, and the introduction of procedures involving small overlaps through bending or controlled 'breaks', known as kerfing, is also essential. Kerfing, in particular, is described as the practice of making strategic cuts in a flat panel to allow it to adapt to the desired three-dimensional curvature. Particularly interesting is the application of these techniques to the hyperbolic paraboloid, a ruled but non-developable surface that represents a case study rich with practical implications.
From the earliest pages, it is evident that the purpose of the text is not limited to the theoretical dimension: on the contrary, its ultimate goal is to guide the reader toward the constructive phase, through a path that links the knowledge of surfaces to their actual manufacturability. In this sense, the parametric approach offers the designer a wide repertoire of configurations and alternatives, which can be selected and adjusted through the variation of parameters and components. *Chapter 5* deals with techniques devoted to prototyping, aimed at simulating complex configurations obtained through kinetic processes that, starting from a flat surface, lead to three-dimensional forms. These virtual models allow experimentation with the fabrication phase as well, offering the possibility to verify and optimize the design. Particularly striking is the reflection on process reversibility, which in theory would allow one to return from the three-dimensional configuration to the two-dimensional one, highlighting the potential of truly bidirectional design.
The section dedicated to kerfing fully demonstrates the effectiveness of this technique in the prototyping phase. The text distinguishes cuts executed on only one side of the surface, suitable for developable forms, from cuts on both sides or through-cuts, necessary for non-developable surfaces. These procedures are made possible by the definition of advanced algorithms capable of managing the application of cutting patterns in relation to the geometric properties of the surface.
The volume concludes with a sixth chapter entirely devoted to applications. At this stage, the focus shifts from theory and the many steps of virtual generation to the concrete dimension of material forms, which demonstrate how the properties of different materials can be exploited within logical processes that are both replicable and adaptable to diverse design needs. Examples drawn from the literature highlight the centrality of developable surfaces, followed by prototypes made from various materials, from polypropylene to plywood to aluminium, showing how each one requires specific considerations.
The text also pays particular attention to strategies for obtaining non-developable surfaces starting from flat elements, mainly presenting two cited approaches: discretization through paneling and the transformation of the surface into developable strips. In both cases, an approximated form capable of following the desired curvature is obtained. While panels and strips are generally made from rigid, non-deformable materials, the author notes that deformable or form-taking materials such as membranes or concrete can also be used, offering greater flexibility and sometimes reversible processes.
In conclusion, *Dal piano alla superficie* demonstrates particular care in combining theoretical principles, operational procedures, and design experimentation.

The clear language and the richness of illustrations support not only the understanding of concepts but also the imagination of variations and adaptations useful in different contexts. The work fully belongs to the field of Architectural Geometry, a discipline that makes geometry the foundation of architectural form, integrating it with computational methods and contemporary production techniques. By focusing on curved surfaces, the text tackles one of the most important themes of Drawing as a discipline, offering readers an approach that is anything but passive: despite the theoretical complexity, the volume provides concrete and replicable examples, making it a valuable tool both for those interested in theoretical aspects, including learners in design education, and for technical professionals wishing to deepen their understanding of the relationship between geometry, design, and construction.

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Reviews

Matteo Flavio Mancini

Esordio, maturità e consacrazione internazionale di Andrea Pozzo. Prospettiva e architettura nei grandi cicli di Mondovì, Roma e Vienna

Fondazione 1563 per l'Arte e la Cultura della Compagnia di San Paolo
Torino 2023
169 pp.
ISBN 9788899808440

The volume by Matteo Flavio Mancini, entitled *Esordio, maturità e consacrazione internazionale di Andrea Pozzo. Prospettiva e architettura nei grandi cicli di Mondovì, Roma e Vienna*, investigates a pivotal theme within both the history of Baroque Art and Architecture, and the visual culture of the 17th and 18th centuries: the œuvre of Andrea Pozzo, a master of *quadratura* and a theorist of perspective. Published in 2023 by the Fondazione 1563 per l'Arte e la Cultura della Compagnia di San Paolo in the *Alti Studi sull'Età e la Cultura del Barocco* series, the book concentrates on a comparative analysis of the three major pictorial cycles executed by Pozzo, correlating them with his treatise *Perspectiva pictorum et architectorum* (*First Part* and *Second Part* of the treatise date from 1693 and 1700 respectively). The overarching objective is to provide a comprehensive understanding of Pozzo's cultural trajectory, emphasizing his adept control and adaptability of methodologies within diverse construction site contexts and amongst heterogeneous workforces.

Matteo Flavio Mancini's innovative approach lies in examining Pozzo's work not only from an art-historical perspective but also utilizing the methodologies of geometric analysis and digital modeling. This results in a new interpretation that elucidates the complex interrelationships between real and illusory space, architecture and painting, theory and praxis, thus offering a more profound comprehension of Pozzo's genius. Furthermore, the extensive iconographic apparatus, encompassing color photography, reconstructive drawings, and three-dimensional models, facilitates an accessible and engaging reading experience, providing interpretation and reconstruction of the real and illusory space of the pictorial cycles under investigation and of the containing mural structures.

The book is structured into four principal chapters, preceded –respectively– by two prefaces contributed by Laura Farroni and Leonardo Baglioni.

The initial chapter delineates the cultural and theoretical background in which Andrea Pozzo's work developed, addressing themes such as the nexus between *architectura picta* and perspective, the symbiosis of art and science in perspective representation, the dialectic between monocentrism and polycentrism in architectural perspectives, and the role of image culture within the Jesuit Order society. Here, Mancini clearly reconstructs the fundamental milestones in the history of perspective, from Filippo Brunelleschi (1377-1446) to Girard Desargues (1591-1661),

demonstrating how Pozzo positions himself within this lineage, inheriting the Renaissance tradition while simultaneously pioneering new avenues for Baroque illusionism. Mancini cogently highlights Andrea Pozzo's position within this panorama, inheriting the theoretical development and artistic experimentation of the 17th century, and anticipating the magniloquence of the 18th, bringing illusionistic virtuosity to its highest levels.
The second chapter focuses on the perspective methods employed by Andrea Pozzo. Mancini analyzes in detail the two 'rules' expounded in the treatise, the 'common rule' (based on distance points) (*Part One* of Pozzo's treatise, 1693) and the 'easiest rule' (based on the intersection of plan and elevation) (*Part Two* of Pozzo's treatise, 1700), highlighting their specific characteristics and practical applications. Particularly interesting is the description of the 'perspectival grid' technique, used by Andrea Pozzo to transfer his designs onto vaulted surfaces. Here, Mancini illustrates how Pozzo adapts his method to different situations, considering the morphology of the surfaces to be decorated, the requirements of the commission, and the cultural context.
The core of the book is constituted by the third chapter, dedicated to the analysis of the three major pictorial cycles, described with philological rigor and excellent interpretive capacity: the works in Mondovì (San Francesco Saverio), Rome (Sant'Ignazio), and Vienna (Jesuitenkirche), reconstructing their history, describing their iconographic content, and analyzing their formal characteristics.
With surveying techniques and digital modeling, Mancini manages to restore the spatial and illusionistic complexity of these interventions, highlighting the perspectival solutions adopted by Pozzo and his relationship with real architecture. The analysis of each cycle is structured into sections concerning the presentation of the work, the description of the perspectival methods used, and the reconstruction of real and illusory space.
In the Mondovì cycle, Mancini emphasizes the importance of the 'altar machine' as a unifying element of the space and as a tool to guide the viewer's gaze. In the Roman cycle, he highlights Pozzo's ability to create a perfect illusion, in which architecture and figures merge into a single vision. Finally, in the Viennese cycle, he emphasizes the monumentality of the intervention and its ability to radically transform the space of the church.
Describing the debut in the church of San Francesco Saverio in Mondovì, Mancini mentions how Pozzo wanted to "cover at least in part the defects" (p. 53) of the church's vault. In particular, he describes the architectural modifications made by Pozzo, including the widening of the windows and modifications to the geometry of the vaults. He subsequently describes the importance of the allegories of the four continents as "witnesses of the saint's mission" (p. 55). The fresco was first rendered three-dimensionally in outline to contact the work, its details, and the artistic gesture. This operation did not reveal the presence of grids for transfer, which, however, must have been used for the passage from sketch to fresco. Based on this evidence, it was decided to operate the reconstruction of the privileged point of view but not to propose a complete three-dimensional reconstruction of the work. Furthermore, regarding the *Apoteosi di San Francesco Saverio*, Mancini highlights how the octagon on which the work is painted is irregular and is grafted onto a system of lunettes and pendentives with an uncertain geometric configuration and poor stereometric coherence (p. 61).
Subsequently, in describing the Roman maturity in the church of Sant'Ignazio, Mancini cites how the false dome was admired and that "some people that were arriving to the door turned back again to contemplate it" (p. 74). The author describes the false dome as a solution to the problem of building a real dome and reports that the work received various criticisms regarding different issues, such as Pozzo's use of large-sized brushes, the overall dark tone of the work, the composition of the architectural party, and, again, the use of full-round columns placed on projecting corbels.
Analyzing the *Allegoria dell'opera missionaria dei Gesuiti*, Mancini describes the theme of the work using the words of Andrea Pozzo, as officially described in a 1694 letter addressed to Prince Anton Florian von Liechtenstein and, subsequently, in the second edition of *Part I* of his treatise published in 1702. The author further clarifies that "the glorification of the ecumenical mission carried out by the Jesuit order is therefore represented through the monumental distribution of figures in space who, from the allegories of the four continents, are redeemed thanks to the work of the Saints of the Society of Jesus" (p. 92).
The fourth chapter draws conclusions from the study, comparing the three cycles and identifying the elements of continuity and the specificities of each. Here, the author emphasizes how Andrea Pozzo managed to create an unmistakable style, characterized by a skillful use of perspective, a great illusionistic capacity, and a profound knowledge of architecture. Specifically, Mancini highlights how all of Andrea

Pozzo's interventions, in addition to the simple activity of decorating the environments, induce a significant expansion of the real space of each church. To fully understand this geometric expedient, Mancini studies in detail (and places in the *Appendix* section) the numerous editions of Pozzo's *Perspectiva pictorum et architectorum* treatise, including a Chinese translation from 1735, the *Shixue*, which is significant for being the first case of systematic exposition in Chinese of European perspective representation techniques. This testifies and confirms how the success of Andrea Pozzo's treatise lay in the numerous editions and translations that appeared over time.

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Reviews

Francesco Di Paola, Andrea Mercurio

Parametric Experiments in Architecture. A Connection Joint Design for Sustainable Structures in Bamboo

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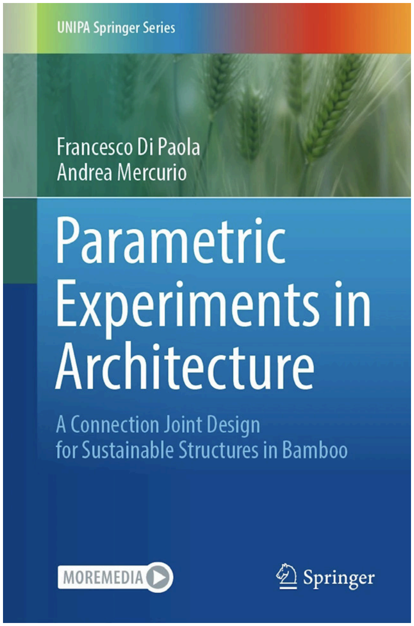

The book by Francesco Di Paola and Andrea Mercurio belongs to a line of research linked to building practices between tradition and innovation. The authors offer a multidisciplinary perspective that reconciles the most advanced techniques of three-dimensional representation and simulation with the science of materials, construction techniques, and structural mechanics. The evolution of the discipline of design, in its transition to the digital age, has highlighted the use of informative 3D models informed by heterogeneous knowledge, thus offering themselves as tools for study rather than for the representation of the buildable. Reading between the lines, we can see how the digital model now offers two main innovations: first and foremost, the possibility of synergistically integrating the components of a project and, consequently, greater computational capacity able to optimize the relationship between the parts. The protagonist of the entire volume, but more generally of the transition from the analog to the digital dimension of architecture, is the concept of parametric modeling, which is suitable for making the designer's choices flexible by transposing reasoning into a function with a certain number of variables.
Similar concepts had already been intuited by Luigi Moretti (1906-1973) in the first half of the 20th century: his writings and projects contain explicit references to 'parametric architecture' and, in particular, to the relationship between form and structure. The first pages of the book analyse some of these general concepts from a historical perspective, recalling, for example, the use of analogue models for structural calculation. In this context, the experiences of Antoni Gaudí (1852-1926) and Frei Otto (1925-2015) are cited, both engaged in researches for optimising the form-structure relationship. These experiments, now referred to as 'form-finding', drew inspiration from nature through the observation of physical models and the materialization of the forces to which they were subjected. Today, digital simulations are inspired by similar principles: this is the case, for example, of the genetic evolutionary algorithms widely used by the authors of the book to create joints for Bamboo structures. The multidisciplinary nature of the volume emerges from the detailed description of the material properties of bamboo, which was used for the research. Ascribed to vernacular architecture, the material demonstrates excellent construction characteristics due to its fire resistance and mechanical qualities: these attributes have led to its intensive use in many geographical areas of the planet suitable for

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its growth. Some attention is also paid to its preparation following the felling of the plant, using natural and chemical techniques. Of particular interest to the focus of the volume is the examination of the state of the art in relation to the methods used to join the elements, from traditional ones, based on the use of knotted ropes, to more engineering-based ones, widespread in contemporary architecture, aimed at designing steel joints oriented in space according to the morphology of the structures. The authors emphasize that the use of this material and the construction techniques associated with it, is currently rather imited especially in Europe, due to restrictive regulations because "there are not sufficient assurances regarding the homogeneity of the mechanical behaviour of the culms, even where these come from the same species" (p. 53).
The main difficulty in designing connection joints for spatial lattice structures lies in the variability of the angles that the coupling elements can assume on the rods converging towards the joints themselves. The geodesic domes of Richard Buckminster Fuller (1895-1983), for example, discretised the problem based on the geometry of elementary polyhedra to obtain a defined number of joint types (variable in number and inclination of the rods) useful for optimizing the production and, subsequently, assembly system. In addition to the above, it should also be noted that the use of bamboo for the construction of the rods involves a possible variability in their diameter, adding an element of complication compared to the use of standardized components for the construction of the edges. Clearly, it is not only a question of considering the geometric complexity of the structure, but also of evaluating a stress distribution that is as homogeneous as possible, given the shape.
More specifically, the authors' goal is to find a design solution that takes into account a number of factors: dry assembly of the structure, in order to simplify assembly and disassembly operations, so as to ensure dimensional adaptability to a specific range of bamboo rod section diameters; the adaptability of the rods that converge at the node in generic directions, to offer the designer the greatest possible formal freedom; the formal continuity between vertices and edges, so that the latter can offer continuity of curvature from a formal point of view and, at the same time, structural balance. The research described led to a solution through a design approach focused on VPL (Visual Programming Language) modelling methodologies and the use of evolutionary genetic algorithms, adopted to optimize the shape of the joints in terms of their mechanical efficiency, under an applied stress. In other words, the FEM analyses conducted guaranteed the morphological solution of the joint optimized in terms of deformation, based on the forces acting on and the displacements undergone by the element. The digital model thus obtained was used to support the creation of a prototype joint made using 3D printing, hypothesizing a possible spatial lattice structure module with rods made from *Bambusa vulgaris*, one of the species of bamboo found in the Botanical Garden of Palermo.
The experience gained by the authors in the field of structures with regular geometries led to further experimentation, this time based on free-form shell morphology, with critical references to the solutions adopted by the Deconstructivist movement. The geometric-design choice for the discretization of the free-form started from a tessellation based on the Voronoi diagram, once again a tool used today in the digital field, but strongly linked to the analysis of natural forms. The subsequent stages of the formal and structural optimization process, as described earlier in the volume, ensured the definition of the joints and rods of the lattice in space, this time characterized by elements that were all different from each other, due to the irregularity of the surface generated. Further examples at the end demonstrate the effectiveness of the process, according to a logical structure that aspires from the particular to the generalization of a method, whose complexity is resolved according to parametric principles.
This contribution is therefore part of a line of research of great interest in the contemporary world, which aspires to reconcile traditional materials and construction techniques, computational design (based on algorithmic optimization) and digital fabrication itself. Underlying these experiences is a remote attitude, on the borderline between engineering and architecture, inspired by the observation of natural forms and the laws behind them, now translated into the digital realm adopting parametric algorithms. Experiences of this kind can only arise from a collaboration between different fields of knowledge, blurring the boundaries between aesthetic characteristics and technological efficiency.

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Events

Events

ICGG2024. The 21st International Conference on Geometry and Graphics

Giovanni Albini

Geometry and Graphics understood both as disciplines and fundamental tools of perception, technique and thought, today embrace an increasingly complex set of research areas. In this context, the *International Conference on Geometry and Graphics* (ICGG) has been a relevant meeting point for the scientific community since 1978, promoting exchange between scholars, professionals and institutions involved in research on the foundations, innovations and applications of Geometry and Graphics. Perhaps the most significant and characterizing aspect of ICGG is its wide multidisciplinary, interdisciplinary and transdisciplinary scope, also evident in this edition, both in the structure of the sessions and in the very nature of the contributions presented and the initiatives proposed.

The twenty-first edition of the biannual conference, the ICGG 2024, was held from August 5 to 9, 2024 at the Kitakyushu International Conference Center, in the city of Kitakyushu, located at the northern tip of the island of Kyūshū, Japan (fig. 1). A particularly significant and heartfelt event for the organizing institution, the ISGG (*International Society for Geometry and Graphics*): in fact, since the eighteenth edition, organized in 2018 at the Politecnico di Milano (Italy), the Conference has not taken place in person, due to the pandemic emergency. About participation, the return to the in-person format after the forced suspension, constituted a significant moment of relaunch, which has received full appreciation from the whole international scientific community. The conference, in fact, was attended by 166 participants from 22 countries. The Japanese context also offered a cultural and environmental component that enriched the event, not only in the scientific content. The large spaces of the Kitakyushu International Conference Center, designed by Arata Isozaki, adequately enhanced by the organizers, contributed to facilitating the interaction among the participants. The excellent structure also cushioned, making them almost imperceptible, the effects of the powerful seismic shock of magnitude 7.1 which occurred on the afternoon of August 8th. The guided tour through some sites in the city –organized on 7 August– allowed us to appreciate the enchanting atmosphere offered by Kitakyushu, a city that surprises the visitor

Fig. 1. Poster of the event.

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Fig. 2. ICGG2024 Opening Session: report by the ISGG President Luigi Cocchiarella and the three-volume proceedings of the ICGG2024 conference.

with the harmony between modernity and tradition, where innovative urban landscapes coexist with quiet corners rich in nature, history and culture.
The *Executive Chair* of the conference was Kazuki Takenouchi (University of Kyushu, former President of the Japan Society of Graphic Science), supported by the two Co-Chairs, Kazuya Kojima and Yosuke Morioka (Kindai University), and by the *Local Organizing Committee*, composed of Kazuya Saito (University of Kyushu), Maiko K. Tsujii (Nishinippon Institute of Technology), Shingo Nakanishi (Osaka Institute of Technology), Takefumi Otsu (Oita University), Tetsuo Kaneko (Kinai University) and Toru Ihara (All Japan Tohsu Technical Association in Civil Engineering). The organization guaranteed a structured and balanced program, considering the different thematic areas. The organization has favored a multidisciplinary debate, highlighted at first by the thematic variety offered by the Opening Lecture, by the four Special Lectures and by a space intended for discussion during the meeting of the ISGG members.
The start of the event, after the greetings of Kumiko Shiina (JSGS, then Vice-President of ISGG) and Liang-Yee Cheng (Executive Chair of ICGG 2022 and ICGG 2020), was in fact the Opening Lecture held by Luigi Cocchiarella (Politecnico di Milano, the President of ISGG) entitled Changes in the ICGG's Conference Topics: *a Pathway Through Geometry and Graphics Over Time, from Descriptive Geometry to Artificial Intelligence*.
The first of the four Special Lectures, entitled *Visual Communication and Entertainment*, was held by Hitoshi Takekiyo, Hiroki Eto and Satoshi Takeno of the Japanese company MontBlanc Pictures. The presentation was enhanced by a connected immersive experience: the *Mobile 3D Ride Attraction*, set up on 6 August at the main entrance of the conference center. Participants were able to board a vehicle equipped with mobile visual attractions, parked next to the conference venue, experiencing, according to the designers' intentions, a sort of 'time machine' capable of stimulating all the senses through stereoscopic images, immersive sound and vibration systems integrated into the seat. The installation was about the world of the animated film *After School Midnighters*, offering a moment of leisure but at the same time consistent with the themes of the Special Lecture, focused on the frontiers of visual communication.
The following one was given by Masakatsu Matsuyama, member of the Matsuyama Architect and Associates, on the topic *Architecture and Design Process*. The two contributions stood out not only for disseminating specific knowledge, but also as expressions of the peculiarities of creativity in Japanese culture: from the original technical solutions in the context of MontBlanc Pictures' *anime* to Matsuyama's testimony on the merits of the design of the villa intended for his parents. The latter, accompanied by images and videos, was particularly engaging, for its ability to convey the design process in every phase, highlighting the intimate relationship between architectural gesture, family memory and cultural sensitivity.
The third Special Lecture, *Geometry and Weaving*, was held by the independent researcher Alison Martin; the fourth and last, entitled *Microgeometry Design, Simulation and Manufacturing*, was offered by Zhenyu Liu (Zhejiang University). Finally, a moment dedicated to the ISGG institutional members –*Meeting of the ISGG Institutional Members and Associated National Organizations*– was organized and moderated by Luigi Cocchiarella and gave rise to the *ISGG Cooperative Mission in the AI Era* round table, focused on the challenges and opportunities that artificial intelligence opens up in the fields of representation and teaching.
131 scientific contributions were selected, out of 173 received from authors from 29 countries. They were divided for being presented into thirty thematic sessions, which took place up to four in parallel, and which ranged from pure and applied mathematics to teaching, up to computational graphics, intertwining a wide range of scientific, technical and artistic disciplines in the common denominators of Geometry and Graphics. A poster session was added to the reports, which collected 13 contributions.
All the scientific contributions were then published in 2025 on three volumes, published by Springer and indexed as Scopus records, entitled *Proceedings of the 21st International Conference on Geometry and Graphics*, in the *Lecture Notes on Data Engineering and Communications Technologies* series (fig. 2). The first volume is divided into three sections: *Theoretical Graphics and Geometry, Graphics Education and Related Topics*. The second

volume is entirely dedicated to the topic of *Applied Geometry and Graphics*: the variety of studies proposed in it is broad and multidisciplinary. A quick look at the contributions included in the volume is sufficient to convey the breadth of the fields of research involved: they range from bio-image analysis studies applied to the morphology of leaves and biomimicry processes, to research on virtual reality, from a study dedicated to the metaphysical spaces in Giorgio de Chirico's painting, up to glitch art experiments generated through artificial intelligence, just to recall some of the trajectories addressed. The third volume is finally divided into the *Engineering Computer Graphics, Geometry and Graphics in History* sections and collects 13 posters.
The conference also hosted a competition. *The International Digital Modeling Contest*, organized by the Japan Society of Graphics Science under the guidance of Hirotaka Suzuki (Kobe University, President of JSGS) and Kensuke Yasufuku (Osaka University, Director of ISGG), took place during the Conference days. The contest aimed to promote fundamental technologies for the creation of three-dimensional mechanisms and objects in innovative environments based on additive manufacturing (3D printing). Ten proposals from three countries were submitted; among these, eight works –together with works already awarded in previous national competitions– were publicly exhibited during the conference.
The convivial dimension of the conference found its culminating moment in the Conference Dinner, which took place on the evening of 8 August at the Art Hotel Kokura New Tagawa. The hotel houses a renowned *shoin-style* garden, designed as a path around a pond and dating back to the Meiji era: a place of great historical and landscape value, ranked 35th in the 2021 Japanese Garden Ranking curated by the American magazine *Sukiya Living Magazine / Journal of Japanese Gardening*, which evaluates around a thousand gardens across Japan. The dinner was further enriched by a traditional Japanese music show, which offered participants an authentic cultural experience that was harmoniously integrated with the atmosphere of the hotel. The last Day, at the Closing Ceremony, the *Steve M. Slaby Award*, the highest ISGG recognition, has been released to Cornelie Leopold (TU Kaiserslautern) and Daniela Velichova (STU Bratislava), for the distinguished scientific contribution in the advancement of Geometry and Graphics in research and education during their university career. The motivation was read by Gunter Weiss (ISGG president 2005-2008). *The Loyal Friends of ICGG Award* has been given by the ISGG President in Office to Cheng Liang-Yee, for the innovation introduced in the Conference organization during the pandemic spread in 2021 and 2022, when the ICGGs took place as online events. At the end of the Conference, it was announced that the next edition, the *22nd International Conference on Geometry and Graphics*, will be hosted in Zagreb (Croatia) from 3 to 7 August 2026. The Conference concluded with the Resolution of ICGG 2024, proclaimed by Yasushi Yamaguchi (ISGG president 2017-2020) and, as per tradition, the event closed with the participants singing the song Auld Lang Syne in chorus, on the soundtrack arranged by Giovanni Albini, and the direction of Gunter Weiss.

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Events

Il Disegno Virtuale del Reale. PhD UID Summer School 2025

Marcello Balzani

The UID Summer School 2025, themed Il Disegno Virtuale del Reale, was conceived as a high-level educational and research experience dedicated to exploring the relationships between representation, technology, and critical interpretation of the built heritage, between symbolism and iconography. The initiative, promoted by the Unione Italiana per il Disegno, took place in Venaria Reale, a city rich in historical and landscape heritage, and in the Drawing TO the Future laboratory of the Politecnico di Torino, a long-established center of innovation applied to the discipline of Drawing.
The title of the Summer School encapsulates a crucial contemporary challenge: to investigate how Drawing –traditionally a tool for understanding and communicating reality– can evolve in a digital and potentially immersive context, while maintaining scientific rigor and a strong capacity for critical interpretation grounded in historical knowledge. In this framework, Venaria Reale offered a complex urban setting where the consolidated city fabric, made up of minor architectures, dialogues with the prestigious presence of the Royal Palace –its buildings and gardens– and with historical and contemporary transformations, while the Polytechnic provided access to advanced technologies and experimental, experiential teaching methodologies. The goal was not merely to acquire skills but to build critical thinking on the role of Drawing in the virtual representation of reality, through an intensive path intertwining theory, practice, and creativity.
The UID Summer School 2025 unfolded as an intensive program characterized by a dense schedule and a strong interdisciplinary component. Professors from various disciplines and twenty-six PhD students from fifteen Italian universities and Tokyo University shared a week of collaborative work, alternating between training sessions, field observations, and laboratory experimentation. The choice of Venaria Reale as an operational setting was deliberate: its historical urban layout and contemporary transformations offered an ideal context to reflect on the relationship between permanence and transformation, architecture and landscape, memory and innovation.

Fig. 1. Poster of the event.

The program was structured around four thematic directions identified by the conceptual tool known as the Compass:

- *The Consolidated City*, to investigate the identity values of the urban form, starting from the historical Via Maestra (now Via Mensa);
- *The City in Transformation*, to analyze the processes of change and the dynamics of resilience and sustainability in contemporary architecture, with particular attention to the project for the new Cultural Hub;
- *The Architecture of Bricks*, to recall the materiality and constructive tradition of the Master of History, exemplified by the Chapel of St. Hubert designed by Filippo Juvarra;
- *The Architecture of the Seasons*, to explore the infinite spatial dimension of the Palace gardens in relation to the surrounding territory and the distant Alps.

These thematic axes served as starting points for a work of critical interpretation, developed through integrated methodologies combining observation, survey, analysis, representation, and modeling.

Theoretical lectures took place both in Venaria Reale and at the *Drawing TO the Future* laboratory at the Polytechnic of Turin an extensive, well-equipped space that integrates a holographic system capable of nullifying distances by projecting remotely connected lecturers as three-dimensional holograms, alongside digital and analog prototyping technologies essential for active experimentation that turns ideas into tangible forms. Here, PhD students could use tools such as 3D printers, modeling software, and manual materials like clay to give physical shape to their theoretical reflections.

The final goal was clearly stated from the beginning: each group was to produce a critical interpretation of the assigned theme, synthesized into an artistic work on canvas (60×60 cm), with no limits on materials or techniques. This piece, far from being a mere creative exercise, represented the conclusion of a complex process in which Drawing reaffirmed its role as a tool of knowledge, communication, and innovation. For this reason, the program was not limited to the technological dimension alone: team-building activities –such as a treasure hunt, puzzle, and the *Compass*– were organized to foster collaboration and problem-solving skills. This playful component, embedded within a scientific context, contributed to strengthening group cohesion and developing transversal skills that are essential in contemporary research.

The final presentation took place on the last day in the scenic Chapel of St. Hubert, a setting of extraordinary historical and symbolic value. Here, through structured pitches, the PhD students illustrated their processes and interpretative choices, clearly demonstrating how Drawing acts as a privileged link between the real and the virtual. The artworks were also digitized and integrated into an accessible and inclusive metaverse, showcasing the intent to transcend physical boundaries and open new perspectives for research and education.

The design process of the UID Summer School 2025 adopted an integrated methodological approach, combining direct observation, critical analysis, and technological experimentation. Activities were structured around a precise daily rhythm: mornings were devoted to the city of Venaria Reale, with on-site visits and lectures; afternoons took place in the *Drawing TO the Future laboratory, equipped for all forms of* physical and digital modeling as well as theoretical integration through physical or holographic interaction.

The tools provided reflected the dual nature of contemporary Drawing: on one side, traditional techniques of representation and manual modeling, such as clay modeling or the use of cardboard, leaves, and threads for critical interpretation; on the other, advanced technologies such as 3D printing, parametric modeling software, and immersive environments for constructing scenarios between the real and virtual. This combination allowed participants to experiment with the continuity between analog and digital, reflecting on Drawing as a mediator between the physical and virtual dimensions.

The method was based on a principle of progressive elaboration: from contextual analysis to the definition of an interpretive concept, culminating in the creation of an artistic canvas designed not only for physical presentation but also for transposition into an inclusive metaverse. This process highlighted how representation is not a neutral act, but rather a cognitive device guiding understanding and communication of the project.

From the outset, the aim of the UID Summer School 2025 was clearly defined: to transform theoretical analysis and practical experimentation into a communicative product capable of synthesizing the complexity of the assigned theme. The twenty-six PhD students were divided into four groups, each dedicated to one of the Compass directions: *The Consolidated City*, *The City in Transformation*, *The Architecture of Bricks*, and *The Architecture of the Seasons*. This organization fostered collaboration, encouraging cross-disciplinary exchange and the construction of a shared vision.

Each group developed an interpretative path structured in phases: field

surveys and data collection, critical analysis, concept definition, and graphic synthesis through analog and digital tools. The outcome was conceived not as a simple creative exercise, but as the synthesis of a research process. The canvas served as the meeting point between craftsmanship and technology, between traditional Drawing and new forms of virtual representation.
The concluding presentation took place in the Chapel of St. Hubert, where each group showcased their work through a structured pitch, demonstrating synthesis, argumentation, and communication skills. The artworks displayed in a unified, yet simple exhibition effectively conveyed the plurality of interpretations emerging from interdisciplinary dialogue. In parallel, the paintings were digitized and uploaded into an inclusive metaverse, designed to ensure accessibility and continuity beyond the physical limits of the event.
To close the day, a theatrical performance curated by Teatro 8 of Turin –a company composed of young people on the autism spectrum– offered a reflection on the value of time as an aesthetic and cognitive dimension. This moment added a profound layer of meaning to the experience, emphasizing how art, in all its forms, can serve as a tool for inclusion and universal dialogue, capable of connecting seemingly distant worlds: the real and the virtual, but above all, the inner one.

The UID Summer School 2025, entitled *Il Disegno Virtuale del Reale*, demonstrated how the discipline of Drawing can play a strategic role in the interpretation and communication of the built environment, within a context where the real and virtual intertwine ever more deeply. The experience highlighted the ability of Drawing to evolve without losing its epistemological identity: from an analog representation tool to a cognitive and technological device, capable of engaging with immersive environments such as the metaverse, while also operating through material and digital prototyping processes.
The group-based structure fostered shared knowledge, grounded in interdisciplinary exchange and the experimentation of integrated methodologies. The choice of Venaria Reale as an operational setting and the Drawing TO the Future laboratory as an innovation hub enabled a productive synthesis between historical and technological dimensions, offering PhD students a unique context to reflect on the relationship between permanence and transformation, materiality and virtuality.
The outcome –the creation of canvases and their transposition into an inclusive metaverse– encapsulated the core meaning of the initiative: Drawing is not merely representation, but critical interpretation, cultural mediation, and a tool for scientific communication. The presentation in the Chapel of St. Hubert and the concluding theatrical performance underscored the value of time as both an aesthetic and cognitive dimension, reaffirming the idea that every project, though projected toward the future, remains deeply rooted in memory and history.
In this framework, the UID Summer School 2025 stands as a model of advanced education, capable of integrating research, teaching, and social impact through experimentation that allows young scholars to harness diverse tools to confront the challenges of representation in the digital age. Far from playing a secondary role, Drawing emerges as the protagonist of an innovative process that encompasses not only techniques, but also the cultural and scientific paradigms of change.

Fig. 2. The PHD students and tutors of the UID Summer School 2025 in Venaria Reale with the final canvases.

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Events

UID2025. *èkphrasis. Descriptions in the Space of Representation.* 46° International Conference of Representation Disciplines Teachers

Paolo Giandebiaggi

From September 11 to 13, 2025, the 46th International Conference of Representation Disciplines Teachers, organized by the *Unione Italiana per il Disegno* (UID), took place in Rome at Sapienza Università di Roma and Roma Tre University. The event was coordinated in close collaboration by faculty members from the Representation departments of the two universities, as well as from the telematic Università San Raffaele Roma, and was held under the patronage of the Institute for Advanced Studies on Heritage. Rome, through its most representative institutions in the Science of Drawing, effectively promoted debate and exchange among hundreds of professors, researchers, and doctoral candidates in the discipline, not only from Italy but also from several international institutions.
The theme around which the organizers intended to engage participants –inviting them to respond to the call launched a year in advance– was that of *èkphrasis*, understood as a "conceptual imprint present in the two main digital methodologies currently undergoing widespread experimentation: procedural algorithmic description, expressed in written or visual language, and, even more evident, the prompting of generative platforms based on Artificial Intelligence". Indeed, history has handed down to us –especially through treatises– the ancient experience of theoretical and methodological description alongside the illustration of architecture, both in its formal aspects and, above all, in its technological and constructional dimensions, aimed at expanding the communication of information for a deeper understanding of the Art of Construction. Today, this term takes on "a broader, more general, and multidirectional form, making it plausible to use the term itself to indicate any expressive form of description and representation, whether verbal and visual, or visual and visual".
The conference therefore focused on the description of theoretical, methodological, and applied aspects of research in the field of Drawing, investigating whether analyses, constructions, and generative carried out through Drawing may be understood as expressions of *èkphrasis* capable of advancing knowledge. It also examined whether drawings, images, and models, including their mutual representation, can be regarded as forms of *èkphrasis*, conceived as rigorous visual, theoretical, and methodological descriptions aimed at revealing new knowledge and opening previously unexplored pathways of inquiry. Within this theoretical framework on description in the field of Representation, the organizers structured the submitted contributions –developed within ongoing research– along qualitative and temporal perspectives, grouping them into three specific thematic focuses. The first topic, on *Memories of the past*, encompassed research on built and intangible architectural heritage, but also extending to the environment, landscape, treatises, historical cartography, history of representation, history of science and the arts, recognition of cultural identity, and identification of theoretical foundations that constitute a legacy useful for implementing contemporary values of knowledge. The second focus, on Challenges of the present, addressed the new needs of contemporary society, providing answers to emerging cultural questions, in relation to sustainability, inclusion, communication, accessibility, standardization, physical prototyping, and digital modeling. Finally, the third focus, on *Visions for the future*, was devoted to defining and testing experimental activities to open new spaces of inquiry, including imaginative and utopian perspectives in the relationship between the sciences, arts and disciplines, experimenting with methods, techniques, and languages to conceive, prefiguring, and design. In response to the call for papers, 224 submissions were received, of which 218 successfully passed the peer

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Fig. 1. Poster of 46° International Conference of Representation Disciplines Teachers. Roma, 11-13 september 2025.

review process and were subsequently published in the conference proceedings. The Conference opened on the morning of September 11 in the Aula Magna of Sapienza University, with institutional greetings from the Rectors of the Roman universities (Sapienza Università di Roma, Roma Tre University), Antonella Polimeni and Anna Lisa Tota, as well as from the Director of the Department of History, Drawing, and Restoration of Architecture at Sapienza University, Daniela Esposito. The UID President, Ornella Zerlenga, who, newly appointed and serving in this role for the first time, addressed the audience with authority and expertise, as well as with understandable emotion, gave the opening of the conference. The President presented the state of the Association and the significance of the annual conference for the entire Drawing community, now approaching its fiftieth year. Carlo Bianchini and Elena Ippoliti, as the principal organizers of the conference at Sapienza University, subsequently presented an overview of the conference's identity, organization, and three-day program. Mario Docci delivered the opening lecture of the Conference –the UID keynote– in his role as Honorary President of the *Unione Italiana per il Disegno*. Focusing on the theme of water culture in the Roman world, the presentation engaged participants with the extensive body of studies conducted over time on aqueducts, baths, and, above all, the most renowned Roman fountains. With the introduction by Maria Grazia Cianci and Graziano Mario Valenti, the conference officially opened.

The first focus, concerning *The Past*, coordinated by Carlo Bianchini and Anna Osello, included 15 presentations by approximately 30 authors. These contributions primarily addressed built architecture, especially of historical and monumental character, but also encompassed painted architecture, significant decorative elements, and landscapes analyzed through two-dimensional reconstructions, digital modeling, BIM, digital atlases, and 3D databases. The second focus, on *The Present*, coordinated by Alfonso Ippolito and Stefano Chiarenza, included 15 presentations by 50 authors. The contributions focused on digital reconstructions of objects and landscapes, digital twins, imaginary spaces, and spherical sequences, as well as algorithmic modeling, VR and AR developments, and applications of Artificial Intelligence. The third focus, on *The Future*, coordinated by Emanuela Chiavoni and Caterina Palestini, featured 15 researchers by 47 authors. It should be noted that this edition of the UID Conference was distinguished by the absence of parallel sessions for research presentations. Instead, the conference adopted a single-auditorium format, designed to maximize attendance and engagement for each presentation and to ensure the broadest possible dissemination of all topics to participating scholars. This approach, however, demanded careful organization of each presentation to allow delivery within a short time (5 minutes) without compromising the clarity, effectiveness, or impact of scientific communication.

The second day of the conference opened at Roma Tre University, in structures renovated for the university's teaching and research activities, with greetings from the Rector, the Director of the Department of Architecture, and the main organizers on site, namely Maria Grazia Cianci and Marco Canciani. The order of the focus sessions was inverted: the program began with *The Future*, continued with *The Present*, and concluded with the Past. The reopened Future focus, coordinated by Marco Canciani and Stefano Brusaporci, featured an additional 10 presentations by over 30 authors, addressing future scenarios through computational descriptions, VR, and generative AI. *The Present* session, coordinated by Maria Grazia Cianci and Francesca Fatta, included 15 presentations by 31 authors. *The Past* focus, coordinated by Giovanna Spadafora and Marco Giorgio Bevilaqua, featured 15 additional presentations by 32 scholars. A further *Past session*, coordinated by Daniele Calisi and Valeria Menchetelli, included 15 more presentations by 30 authors. Overall, the presentations expanded the concept of representation by addressing a variety of themes and modalities –managerial, symbolic, and narrative– across historical and contemporary contexts. They further extended the notion of representation to include sensory descriptions of a wide

range of content, employing diverse and multidirectional forms, in line with the concept of *èkphrasis*, as defined by the conference.
During the conference, several other talks were presented: Michele Cometa from the University of Palermo and the artist Kristin Jones delivered a lecture on *Surveying the Invisibl*e; Laura Farroni, Marcello Balzani, and Alessandro Luigini gave a presentation on research, innovation, and enterprise; and Anna Osello led a session on the outcomes of the PHD Summer School UID 2025 held in Venaria Reale (Turin), entitled *The Virtual Drawing of the Real*. The conference also featured collateral events, such as Urban Drawing along the avenue of the university campus in front of the main conference venue, as well as exhibitions of drawings, projects, and research outcomes from the teaching and research activities of the 'Roman' faculty members in the Representation area. The 2025 UID Young Researchers Vito Cardone Award was awarded to ∀*ISION_E – Drawing: A Vision for Every Extended Intelligence*, coordinated by Enrico Pupi. The project was selected during the summer as part of the exhibition of results.
On Saturday, September 13, following the presentation of the best papers awards for the individual sessions, the Congress of the Faculty Members –that is, the general assembly of the UID Scientific Association– took place. During this assembly, President Ornella Zerlenga presented the numerous initiatives launched over the past year, the work carried out by the Technical-Scientific Committee, and the perspectives for 2026, including a presentation by Marcello Balzani on the 47th UID Conference, which will be held in Ferrara in 2026. During the final morning, Francesca Fatta, Paolo Giandebiaggi, and Carlo Bianchini awarded the traditional UID Gold Plaques to Ornella Zerlenga, Laura De Carlo, and Guendalina Salimei, respectively. Guendalina Salimei, Professor of Architectural Design at the Roman University and a renowned architect, also presented to the participants the major works completed during her career.
During the assembly, a highly attended and emotional moment was dedicated to the memory of Massimiliano Ciammaichella, colleague and member of the Association's Technical-Scientific Committee, who passed away far too prematurely during the summer. Both the President, who recalled Massimiliano's commitment and the main achievements of his academic career, as well as his empathetic and enthusiastic character, and Graziano Mario Valenti, through a special dedication, sought to honor him through various initiatives. It was decided to dedicate the proceedings of this Roman conference to Massimiliano, as a testament to his vivid and enduring memory, along with other future initiatives that UID plans to carry out.
The assembly concluded to full satisfaction of the participants, with heartfelt thanks to the organizers and a warm farewell to all members and supporters, with an invitation to attend the next conference in Ferrara, to be held from September 10 to 12, 2026, entitled *Furious Drawing*.

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Events

APEGA 2025
Pensamiento Grafico entre Docencia, Representación e investigación

Emanuela Lanzara

From October 2nd to 4th 2025, the Escuela Técnica Superior de Arquitectura y Edificación (ETSAE) of the Universidad Politécnica de Cartagena (UPCT) hosted the *Congreso Internacional de Expresión Gráfica Aplicada a la Edificación* APEGA 2025 [1]. The biennial event has reached its XVII edition. The conference theme, *Pensamiento Grafico/Graphic Thinking*, refers to the process that evolves from conceptual synthesis to the representation of reality.

The event was mainly held in the panoramic Salón de Actos Isaac Peral, the venue for the two plenary sessions located on the third floor of ETASE with access from Calle Real, just a few steps from the Plaza del Ayuntamiento and offering an all-round view of the intense and dynamic maritime landscape of the Puerto Comercial of the city.

In the foyer outside the hall the Exposición Edigráfica was installed as part of the congress and remained accessible throughout the entire event. At each edition, the selected works published in the Exhibition Catalogue compete for the Concurso *Juan Manuel Raya*, established to reward the best educational and research works in the field of the *Expresión Gráfica aplicada a la Edificación*.

Among the 88 selected contributions, 51 were presented during the two-day of the conference, involving a total of 192 authors from Spain, Italy, and Latin America.

LINEA 1. Docencia y Metodología/Teaching and methodology collected 22 contributions dedicated to teaching methods and graphic expression exercises that highlight the teacher's mastery and skill. *LINEA 2. Trazo y Representación/Drawing and Representation*, included 23 contributions on the process of conceptualisation and graphic representation, with a clear emphasis on the importance of representational quality. Finally, *LINEA 3. Investigación y Difusión/Research and dissemination,* consists of 43 contributions aimed at advancing research and development of graphic thinking in the artistic, architectural and engineering fields.

During eight mixed plenary sessions participants presented ten-minute talks on theoretical and applied studies covering a wide range of interdisciplinary topics, with Cultural Heritage as the main field of investigation and experimentation.

At the opening ceremony the event was introduced by institutional greetings of the members of the Honor Committee, including Mathieu Kessler Neyer, Rector of UPCT, who emphasized the fundamental role of academia in the dialogue between professional practice and teaching, José Antonio Barrera-Vera (Departamento de Ingeniería Gráfica dell'Universidad de Sevilla), President of the Asociación de Profesores de Expresión Gráfica aplicada a la Edificación APEGA, Antonio Caballero Pérez, CEO of the Universidades de la Comunidad Autónoma de la Región de Murcia (CARM), Antonio Mármol Ortuño, President of the Colegio Oficial de Aparejadores, Arquitectos Técnicos e Ingenieros de Edificación de la Región de Murcia y de Musaat (COAATIEMU), Fernando M. García Martìn, Head of the ETSAE and Ornella Zerlenga, Head of the Department of Architecture of the Università della Campania Luigi Vanvitelli and President of UID, Unione Italiana per il Disegno.

The scientific committee opened the proceedings with the presentation of the *Juan Manuel Raya* Aword to Diego Celis-Estrada, Pablo Rodríguez Navarro e Teresa Gil Piqueras (Departamento de Expresión Gráfica Arquitectónica de la Universidad Politécnica de Valencia) for the work *De los planos históricos a la precisión digital: Metodología fortogramétrica y SIG para la localización y documentación de estructuras defensivas virreinales*, published in detail in the *Edigráfica* Catalogue, while the second prize went to Chiara Vernizzi e Virginia Droghetti (Department of Engineering and Architecture, University of

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Fig. 1. Logo/flyer of the event.

Parma) for the graphic work presented during the exhibition and published in the contribution *Graphic Design in the Communication or Architecture projects. Considerations on targeted educational experiences*. Sixteen tables, organized into eight categories, illustrate the results of the Architecture Visualization course: based on Munari's study of harmonic structure, this activity explores how the composition and management of graphic elements, such as color, light and shadow, influence visual communication, demonstrating how students adapt established theoretical principles to personalized visual languages. The three sessions on the first day, one in the morning and two in the afternoon, were chaired by Amparo López Bernal-Sanvicente (Universidad de Burgos), Mercedes Valiente López (Universidad Politécnica de Madrid) e Ruth Pino Suarez (Universidad de La Laguna).

The first session was introduced by the keynote lecture *Pensar con el lápiz en la mano* by architect, graphic designer, painter and sculptor Vicente Martínez Gadea, member of the Royal Academy of Fine Arts of Santa María de la Arrixaca. The Murcian architect shared his experience with the audience, explaining how his thoughts and creativity find expression through the act of manual drawing. He retraced his formative years spent between the Faculty of Architecture and the Academy of Fine Arts in Madrid and he explained the main graphic influences that guide his architectural and pictorial work.

The presentations given throughout the day shared a common theme: drawing as a cognitive tool, between training, design and memory. Educational experiences, from BIM to virtual pavilions, from play-based approaches to complementary learning strategies, demonstrate how analogue and digital representation has become a laboratory for heterogeneous technical and critical skills. 3D Scanning, Gaussian Splatting, and Information Modelling are combined within a systemic framework oriented towards Digital Heritage, aimed at revealing latent geometries and identities of place in which graphic design acts as a bridge between past, future hypotheses and imaginary scenarios.

During the second day, the four morning and afternoon sessions were moderated by José Antonio Barrera Vera (Universidad de Sevilla), Pablo Juan Jeremías Gutierrez (Universidad de Alicante), Juan Saumell Lladó (Universidad de Extremadura) e Antonio Miguel Trallero Sanz (Universidad de Alcalá). The topics ranged from integrated digital surveying experiments to generative AI applications in a continuous dialogue between technological innovation and critical interpretation. CAD, BIM, GIS, generative and computational modelling are combined by immersive educational and exhibition strategies, outlining a framework in which representation emerges as the main tool for documenting knowledge and memory, building new possibilities for Heritage and contemporary design.

After lunch, held in the ETSAE cloister, David Martínez (ISCAR *Software de Arquitectura*) gave a presentation entitled *De la innovación CAD hacia el ingenio IA&BIM*, which introduced the afternoon sessions and provided an overview of the most widely used digital tools in design, including current and emerging trends and the integration of workflows and innovative tools for 3D modelling, real-time visualization and AI support, emphasizing the role of BIM in supporting the management of complex processes. The day ended with cocktails and dinner at The Batel Auditorium & Convention Centre, designed by SelgasCano

and located along Cartagena's seafront. Finally, on the morning of the third day, participants had the opportunity to take part in organized visits to the Roman Amphitheatre of Cartagena and the Palacio Casa Tilly, guided by José Antonio Rodríguez Martínez (JARM Arquitectura y Patrimonio [2]).
In summary, the XVII edition of the APEGA 2025 Congress highlighted the central role of *Pensamiento Gráfico* as a cognitive process aimed at integrating analysis, representation and design.
In detail, *LINEA 1. Docencia y Metodología*, presented a series of experiences resulting from the integration of analogue and digital approaches, supporting a replicable holistic educational model grounded in a balance between theoretical rigor, practical experimentation, technological innovation and emotional engagement. Part of the studies showed how direct observation enhances spatial perception, visual sensitivity and contextual understanding, from the emotional and hand-drawn life experiences developed in Genoa, Bologna, Brescia and La Plata, to the documentation of theatres and cinemas in Catania. The use of interdisciplinary teaching approaches based on Information Modeling, gamification and collaborative workshops emerge, engaging students as active cultural promoters. The integration of advanced technologies, BIM/HBIM, integrated digital surveying and VR/AR supported by a problem-solving oriented pedagogical approach, fosters the development of transversal skills. Other contributions propose the adoption of innovative teaching methods aimed at strengthening the understanding and visualization of space, from the construction of analog pop-up models for 3D illustration to digital VR experiments for the reconstruction of the Roman Baths of Lugo. Part of the work investigates theoretical aspects, from the geometric-descriptive study of shape to Turner's pedagogical method, between linear and aerial perspective. Other studies offer technical-constructive insights, from the analysis of Hispano-Muslim truss carpentry to the cartographic techniques for urban planning.
LINEA 2, Trazo y Representación, collects the results of the integration of survey, representation, modeling and communication, from 3D printed models of the cathedrals of Girona and Narbona, to the acquisition and interpretation of the oval cloisters of Palma de Mallorca and Naples, and finally to the integrated survey, combining photogrammetry and Gaussian Splatting, of the *Sala Terrena* of the Scuola Grande di San Marco, aimed at producing immersive models.
Other contributions collect experiences of multiscale analysis and restitution, from the mapping of Guadalajara's urban Heritage, carried out in the 19th century by the National Geographic and Statistical Institute, to the interdisciplinary analysis of human-environment interaction in the Palladian landscape of the town of Piazzola sul Brenta; from the historical and graphic documentation of *Les Cavallerisses*, the ancient stables of the Hermitage of the Virgin of Grace in Vila-real, to the geometric study of Gaudì's Escuelas and the Universal Design approach for the creation of tactile models and inclusive applications for the enhancement of the Garisenda Tower in Bologna. A further group of works explores configurations, geometries and archetypes that characterize architectural and artistic Heritage, including the Cosmatesque flooring of Salerno Cathedral, the differentiated staircases of Palazzo Ricca/Cuomo and the Royal Palace of Capodimonte in Naples, the neo-Egyptian apparatus of the Schilizzi mausoleum, and the reuse of Egyptian and Greek archetypes in the work of Juan Borchers Fernández. On the educational front, this line presents experiments in transforming Soviet avant-garde art into physical models, the use of comics to narrate architectural works and projects, the use of VR and Metaverse platforms to facilitate the management and understanding of architectural projects, the development of scripts for generating oblique axonometric projections and 3D printing of recyclable modular bricks made of thermoplastic material. The digital reinterpretation of Perugino's fresco of the *Martyrdom of Saint Sebastian*, between real and illusory architecture, and the comparison between the strategic perspective distortions of Pérez Villalta and Tintoretto emerge among the studies aimed at perspective analysis.
LINEA 3, Investigación y Difusión, among the numerous dedicated contributions, presents a set of experiences focused on the analysis, documentation, and management of Cultural Heritage. From the seismic vulnerability assessment of the monastic complex of Montecassino, to the digital documentation of the Church of San Andrés in Adamuz and the Castle of Monteagudo; from the surveying activities aimed at the restoration and enhancement of Villa Amparo in Rocafort, to the digitization of the Nabatean Arch of Bab as-Siq in Petra in Jordan.
The altarpieces of the Basilica of Nuestra Señora del Prado in Talavera, the timber roof of the Church of Santiago el Mayor in Totana, the Mudéjar corbel of San Antonio Abad in Valencia, the Ermita del Pilar in Catí, the polychrome spires and domes of Acireale and Valencia, the Neapolitan domes and the late Gothic portals of Geldo, Sot de Ferrer, Alfara, Oliva, and Geldo are digitally documented and analyzed to reconstruct

their graphic compositions and geometric layouts, aimed at supporting appropriate conservation strategies.
The study of the ancient mathematical writings of Johan Ludvig Heiberg and Hero of Alexandria supports a renewed interpretation of ancient architectural design. Research on to the eclectic production of Velázquez Bosco in Guadalajara, the Portada del Mexuar, Antonio Bonet Castellana's Water Pavilion, and the Pilar y Joan Miró Foundation investigates these works and spatial constructs by examining their geometry, compositional logic and modularity.
The Ligurian mills and the Mediterranean fortifications across Italy, Spain, and Turkey are analyzed and documented as 'imprints of memory'; the graphic documentation of the XIX century Cuban cemetery and the analysis of the unrealized cemetery project in Valencia support typological studies and contribute to the enrichment of archival resources; the digitalization of the Baths of Baiae complex in Bacoli extends the investigation to archaeological sites.
The enhancement of the *Feria de Abril* gates in Seville and the installation of the inclusive, sensory Nativity scene designed by the Polytechnic School of Cáceres interpret the ephemeral as a set of devices for cultural and identity-based inclusion.
Some of the experiments propose multilayered prototyping: from the digitization and 3D printing of Salzillo's angel at Santa Clara in Murcia, to the physical reproduction of ballistic traces preserved on the northern walls of Pompeii; from the digitization, prototyping and AR/VR musealization of the nineteenth-century Gillow & Co. Furniture, to the construction of moodboards designed to guide AI image generators.
Finally, a series of contributions address digital innovation in support of Heritage design and management: from BIM for 3D Printing strategies for housing prototyping in Chile, to the investigations of the historical development of 3D mortar printing; from Scan-to-FEM-Ready BIM processes structured in Burgos, to reparceling and urban management; from GIS/BIM interoperability to BIM/circular-economy integration. The overview is completed by studies focused on the design and production of smart glass, as well as on the functional and aesthetic role assumed by color in contemporary swimming pool design.
In conclusion, between teaching and research, the event charted a shared collective course focusing on the convergence between tradition and innovation and delineating a scenario in which graphic thinking assumes the role of a holistic and inclusive tool for knowledge, memory and sustainability.
The proceedings of the conference, edited by Josefa Ros Torres and Gemma Vàsquez Arena [3], are available in open access in the UPCT online repository [4].

Notes

[1] Universidad Politécnica de Cartagena (2 octubre 2025). Los expertos destacan el impacto de la innovación tecnológica en la Expresión Gráfica. <https://www.upct.es/noticias/2025-10-03-los-expertos-destacan-el-impacto-de-la-innovacion-tecnologica-en-la-expresion-grafica> (accessed 29 November 2025).
[2] JARM. Arquitectura y Patrimonio: <https://jarm-arquitectura.com/somos/> (accessed 29 November 2025).
[3] Ros-Torres, J., Vázquez, G. (Eds). (2025). *Graphic Thinking. XVII International Conference on Graphic Expression Applied to Building APEGA 2025*. Conference Proceedings. Cartagena, 2-3-4 October 2025. Cartagena: Universidad Politécnica de Cartagena. Ediciones UPCT. ISBN: 978-84-95781-52-9. DOI: 10317/18884
[4] The UPCT digital repository is available at the following link: <https://repositorio.upct.es/entities/publication/64a85321-c9c3-492a-b2be-3ff3db209f55> (accessed 29 November 2025).

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Events

Alghero Week 2025

Valeria Menchetelli

From July 1st to 4th 2025, the Alghero's Department of Architecture, Design and Urban Planning of the University of Sassari hosted a series of scientific events of considerable relevance for the Drawing community. Once again, these initiatives highlighted the dynamism and vitality of the solid and cohesive research group affiliated with the Laboratory of Graphic and Visual Sciences (GRA•VIS lab), coordinated by Enrico Cicalò and composed of Michele Valentino, Alexandra Fusinetti and Andrea Sias.

Borrowing a designation commonly used for major cultural and artistic events, this set of initiatives is intentionally brought together here under the concise title 'Alghero Week 2025', underscoring its character as an organic program unified by a common guiding thread.

The dense program of activities, comprising four conferences, seminars, and exhibition events, opened on the afternoon of July 1st with the exhibition *NurACHe. Nuragic Architectural Cultural Heritage. Surveying, Representation and Modelling*. This exhibition inaugurated a cycle of events presenting the research activities of the Department of Architecture, Design and Urban Planning of the University of Sassari in support of the process aimed at recognizing the monuments of Nuragic civilization within the UNESCO World Heritage List.

Curated by Enrico Cicalò, Michele Valentino and Alexandra Fusinetti, the exhibition was introduced by a presentation of the experimental activity promoted by the Department which, through the integration of advanced methods and tools, investigated a selection of eleven monumental architectures of Nuragic civilization, contributing to the nomination process for inscription on the UNESCO List. Specifically, *NurACHe* presented the results of an integrated survey campaign, based on the use of aerial photogrammetry and laser scanning methods, conducted between April and June 2024. The collected data opened the way to the exploration of innovative modes of representation and site enjoyment, as well as enabling the production of communicative and educational models through 3D printing. The eleven investigated sites –comprising sacred architectures, Nuragic sanctuaries, complex villages, Nuragic keeps, sacred wells and springs, Giants' tombs, and megaron temples– previously unexplored through the potential offered by digital technologies, thus became the focus of a research path oriented towards key themes for the scientific community of representation, such as virtual archaeology, digital reconstruction, accessibility, communication, and the enjoyment of cultural heritage.

The exhibition initiative, followed in subsequent months by further accompanying events supporting the nomination process, confirmed the indispensable contribution of representation both in the construction and deepening of scientific knowledge and in the interpretation, updating, and technological enhancement of the ways in which information and cultural sites are accessed and experienced.

The day of July 2nd 2025 was dedicated to the final presentation of the outcomes of the project *Graf_I - Graphics of Intangibility. Representation for the narration of intangible culture*, winner of the fifth edition (2024) of the UID Giovani Prize dedicated to the memory of Vito Cardone. The project was conceived and promoted by a large and passionate group of young researchers affiliated with the scientific society Unione Italiana per il Disegno (Andrea Sias, Nicola La Vitola, Sonia Mollica, Flavia Camagni, Luca Martelli, Sonia Mercurio, Johan Sebastián Wilches Rivera, Simone Sanna, Luca Vespasiano, Alma Benítez Calle), belonging to five universities

Fig. 1. Exhibition opening poster of NurACHe. Nuragic Architectural Cultural Heritage. Survey, Representation and Modelling. Alghero, July 1st 2025.

Fig. 2. Logo of the study day Graf_I - Grafie dell'Immaterialità. Representation for the narration of immaterial culture. Alghero, July 2nd 2025.

(Sapienza University of Rome, Politecnico di Bari, University of L'Aquila, University of Sassari, Mediterranea University of Reggio Calabria), and skillfully coordinated by Andrea Sias (University of Sassari).
The idea underlying the project offered an innovative interpretation of the theme 'Taking Care: Drawing for Well-being and Safeguarding', proposed by the 2024 UID Giovani Prize call, focusing on the role of drawing as a privileged language for narrating those identity-defining cultural elements which, due to their intrinsic intangibility, most require attention and 'care'. The project was thus devoted to the multiple forms and expressions of intangible cultural heritage, which today remains a field still scarcely investigated and documented, representing a highly topical and stimulating challenge for the discipline of Drawing. As a repository of traditions and practices sedimented throughout the history of communities and civilizations, intangible heritage constitutes a fragile field of study due to its immaterial condition and the lack of codified methods and tools for its representation, cataloguing, and communication. Recognizing the value of the intangible aspects of heritage therefore represents the first step towards defining shared practices aimed not only at safeguarding but, above all, at transmitting them to future generations, an essential requirement for the survival and renewal of these traditions.
The *Graf_I* project involved the scientific community through a call for images, a further distinctive feature of the initiative that set it apart from the more common call for textual contributions. From the outset, the choice was oriented towards enhancing the image both as a document and as a communicative vehicle of the act of care undertaken towards intangible heritage. As highlighted by Edoardo Dotto in the Preface to the volume –published by Publica– collecting the project's outcomes, the radical choice was to build a reflection starting from a single image, for which the text functions as an extended caption.
The collection of contributions thus becomes a visual mosaic even before a verbal one, communicating the variety and complexity of a rich and articulated heritage that calls to be discovered and explored. This mosaic is effectively conveyed both by the final volume –structured around three thematic focuses reflecting the current use of representation tools (Analog Graphics, images produced through traditional drawing techniques; Digital Graphics, representations created in digital environments; Photo-Graphics, images produced through photographic techniques)– and, during the Alghero events, by the exhibition set up in the Department's spaces, which enhanced the dialogical relationship among different forms of cultural expression and the evocative power of a collective narrative composed solely of images.
The concluding invitation to take away a small selection of the plates included in the volume further strengthened the profound sense of commitment to preserving, disseminating, and safeguarding elements of intangible heritage, extending the gesture of care across space and time. Following the exhibition opening, the study day included invited lectures by Mona Hess, head of the Chair in

Digital Technologies in Heritage Conservation at the University of Bamberg; Gianna Saba, official of the Superintendency for Archaeology, Fine Arts and Landscape for the provinces of Sassari and Nuoro; and Alessandra Sento, Director of the Centro Società Umanitaria Alghero. These were followed by a roundtable discussion in which several voices from within the field of representation (Ornella Zerlenga, Francesca Fatta, Marcello Balzani, Carlo Bianchini, Stefano Chiarenza, Valeria Menchetelli, Sandro Parrinello) contributed to the debate on the significance of the *Graf_I* project outcomes.
The disciplinary and extra-disciplinary perspectives opened by these contributions reaffirmed how intangible cultural heritage represents a fertile field of investigation and how the project initiated within the UID Giovani Prize context lends itself to productive future developments, as further confirmed by the recent launch of the call for images for the second edition, entitled *Architectures without body. Fragments, memories and imaginations*, whose concluding event is scheduled for June 2026.
The third of the Alghero events took place on July 3rd and 4th with the fourth edition of the *DAI* conference, which on this occasion changed its title from *Drawing for Accessibility and Inclusion* to *The Drawing of Accessibility and Inclusion*.
This event, now a well-established forum for reflection and a point of reference for the Drawing scientific community in relation to accessibility and inclusion, is promoted annually by a group of professors (Marco Giorgio Bevilacqua, Cristina Càndito, Enrico Cicalò, Tommaso Empler, and Alberto Sdegno) with the aim of engaging scholars and researchers in design-oriented dialogue and in the ethical commitment required by the conference themes, reflected in the exhortative acronym *DAI* derived from the title's key words.
The 2025 edition builds upon a reflection on the contributions received in the first three editions and marks a shift from the collection of experiments and case studies primarily aimed at providing methodological tools, towards a scientific debate focused on concrete and operational design responses to emerging societal issues in the fields of accessibility and inclusion. This fourth edition thus predominantly recognizes the design dimension that drawing assumes in responding to community needs and demands, through solutions consisting of graphic representations, three-dimensional models, digital environments, and visual communication strategies, resulting from research grounded in advanced theories and technologies. Alongside the now-established thematic focuses of the conference –dedicated to spatial, socio-cultural, cognitive, psycho-sensory, and museum-related dimensions of accessibility and inclusion– the 2025 edition is distinguished by the addition of a further thematic area devoted to accessibility and inclusion in outdoor cultural heritage sites.
This choice, motivated by the territorial characteristics of the Sardinia Region, which has the highest number of parks and archaeological areas in Italy, proved to be of great interest and welcomed studies and research from various Italian universities. The journey among the venues that hosted the conference (Genova in 2022, Udine in 2023, Roma in 2024, and Alghero in 2025) has thus enriched the debate

Fig. 3. Poster of the conference DAI - The Drawing of Accessibility and Inclusion. Alghero, July 3rd-4th 2025.

with new themes, updating research perspectives and gathering disciplinary and interdisciplinary interests that are continuously renewed over time. The conference sessions were enriched by two invited lectures of extra-disciplinary content, intended to offer stimuli from perspectives external to the field of Drawing.
In particular, the lecture *Graphic Medicine: comics in dialogue with care*, introduced by Alexandra Fusinetti and delivered by Stefano Ratti –full professor of human anatomy at Alma Mater Studiorum - University of Bologna and president of the Graphic Medicine Italia Association– opened a debate on the role and importance of comics, one of the most immediate

Fig. 4. Poster of the seminar M.A.C.IN.A. Multilevel Application for Cultural INformation Archives. Alghero, July 4th 2025.

and engaging graphic languages, in the medical and healthcare fields, where they are now regarded as a fundamental communicative, educational, and awareness-raising medium for topics still considered difficult to address, including from an ethical standpoint.
The lecture *Designing the Enjoyment of Universal Heritage. A Design Manual for Accessibility to Cultural Sites*, introduced by Michele Valentino and delivered by Gabriella Cetorelli, official of the Direzione Generale Musei and responsible for Accessibility to State Cultural Heritage, provided an overview of accessibility to cultural heritage sites by presenting the contents of the *Design Manual for Accessibility and Expanded Enjoyment of Cultural Heritage. From Human Functioning to the Functioning of Cultural Sites*, published in 2024 by the Department of Human and Social Sciences, Cultural Heritage of the National Research Council. The manual aims to provide operational tools and regulatory references for informed and sustainable design. As with *DAI* 2025, the substantial conference proceedings volume is available in open access on the Publica publishing platform.
The afternoon of July 4th was finally devoted to the study seminar organized within the framework of the project *M.A.C.IN.A. - Multilevel Application for Cultural INformation Archives*, funded under the PRIN 2022 PNRR call and involving a partnership between the Institute for Construction Technologies of the National Research Council (Principal Investigator Ilaria Trizio), the Department of Architecture, Design and Urban Planning of the University of Sassari (Associated Principal Investigator Michele Valentino) and the Department of Earth, Environmental and Resource Sciences of the University of Naples Federico II (Associated Principal Investigator Silvia Fabbrocino). The research project, focused on the conservation, management, and communication of the cultural heritage of the inner areas of the Abruzzo and Sardinia Regions, adopts an innovative methodological approach integrating technologies such as HGIS (Historical Geographic Information Systems) and HBIM (Historic Building Information Modelling) to define an HLIM (Heritage Landscape Information Modelling) model. The aim is to provide a multidimensional analysis of the relationships between built heritage, the environment, and hydrogeological dynamics, thereby promoting sustainable and informed territorial management. The program, following the presentation of the project by the leaders of the research units, included invited contributions by scholars from several Italian universities (Sapienza University of Rome, University of L'Aquila, University of Florence, University of Padua, University of Naples Federico II, University of Pisa) whose research focuses on digital information models for historic architecture, landscape representation and communication, and geological investigation aimed at enhancing the cultural heritage of inland areas. The concluding roundtable, coordinated by Ornella Zerlenga, President of the Unione Italiana per il Disegno, brought together Marco Giorgio Bevilacqua, Stefano Brusaporci, Emanuela Chiavoni, Silvia Fabbrocino, Andrea Giordano, Roberto Graziano, Sandro Parrinello, Ilaria Trizio, Michele Valentino, and Ornella Zerlenga in a fruitful discussion on the potential of digital technologies for the future of cultural and landscape heritage conservation and enhancement.
Taken as a whole, the events that marked 'Alghero Week 2025' provided an organic and meaningful overview of the scientific and cultural vitality of the GRA•VIS lab Laboratory of Graphic and Visual Sciences active in the Alghero site and, more broadly, of the entire Drawing community.
The richness and variety of the proposed initiatives confirmed the central role of representation as a critical tool for knowledge, interpretation, and design, capable of addressing in a conscious and innovative manner the challenges posed by tangible and intangible cultural heritage, accessibility and inclusion, sustainability, and the communication of territory and

landscape. In this sense, the Alghero program was configured not only as a moment for presenting mature and articulated research outcomes, but also as an open space for dialogue, capable of fostering new research perspectives and strengthening scientific and design networks destined to further develop over time.

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Events

Nexus 2025
Relations Between Architecture and Mathematics

Maria Zack

The international conference *Nexus 2025: Relationships Between Architecture and Mathematics* convened from June 3-6, 2025, in the historic city of Andrea Palladio, Vicenza, Italy. Continuing a tradition of innovative interdisciplinary research, this year's meeting was hosted by the Department of Civil, Environmental, and Architectural Engineering (Ingegneria Civile Edile e Ambientale, ICEA) of the University of Padova and held in the elegant Palazzo Barbaran da Porto, the headquarters of the Palladian Museum.

Conference co-directors Kim Williams (Founder of Nexus) and Cosimo Monteleone (Professor at Università degli Studi di Padova) collaborated with a dedicated planning team and scientific committee to organize four days of intensive scholarly exchange.

The Nexus conference series, which fosters dialogue on the intersection of architecture and mathematics, began in Fucecchio, Italy, in June 1996. Subsequent meetings have been held every two years: 1998 in Mantua, Italy; 2000 in Ferrara, Italy; 2002 in Óbidos, Portugal; 2004 in Mexico City, Mexico; 2006 in Genoa, Italy; 2008 in San Diego, USA; 2010 in Porto, Portugal; 2012 in Milan, Italy; 2014 in Ankara, Turkey; 2016 in San Sebastián-Donostia, Spain; 2018 in Pisa, Italy; 2021 in Kaiserslautern, Germany (but held online due to the COVID pandemic of 2020) and 2023 in Torino, Italy. The 2025 gathering in Vicenza marked the continued growth of this international community, bringing scholars together to present research and engage in wide-ranging conversations.

The first day commenced with formal welcomes from the co-directors, Kim Williams and Cosimo Monteleone. Guido Beltramini, Director of the Centro Internazionale di Studi di Architettura Andrea Palladio (CISA Andrea Palladio), welcomed the participants to Vicenza and Andrea Giordano, Professor at Università degli Studi di Padova and Dean of Civil, Environmental and Architectural Engineering Department, provided a welcome on behalf of the University. Ornella Zerlenga, Professor at the Università degli Studi della Campania Luigi Vanvitelli and President of Unione Italiana per il Disegno (UID), sent greetings on behalf of the scientific and cultural association.

The scientific program began with the keynote lecture, *Palladio's soave armonia*, delivered by eminent Palladian scholars Guido Beltramini and Deborah Howard. This lecture offered critical insights into the architecture of the Veneto during Palladio's era, effectively establishing a thematic connection between the conference's core topics and its historical setting in Vicenza.

Following the keynote, the conference proceeded with contributed paper sessions. The extended abstracts of the presentations can be found in *Nexus 2025 Relationship Between Architecture and Mathematics Conference Book.*

Day one centered on architectural analysis and mathematics behind design. Sessions titled *Architectural Analysis I and II* focused on the examination and interpretation of numerical and geometric principles in specific structures. The case studies were wide-ranging, covering the design work of Frank Lloyd Wright, Andrea Palladio, Aldo Rossi, Kazunari Sakamoto and Carlo Scarpa. The second session employed geometric analysis and digital reconstruction to interpret historical architecture and texts, including Guarini's Chapel of the Holy Shroud, Girona Cathedral, and military architecture treatises from the 16th and 17th centuries. The session *the Mathematics Behind the Design* explored the underlying mathematical structures used in architectural design, often utilizing computational tools to analyze structures such as Gothic cathedrals, medieval monasteries, and Byzantine brick vaults.

Day two began with the session *Algorithmic Design*, which addressed

Fig. 1. Poster of the event.

the application of algorithmic, computational, and recursive methods to architectural modeling including soft curved folding and Gothic microarchitecture. This session *Rule-Based Design* followed. The session focused on generating and analyzing architectural forms using formal systems such as shape grammars and classification rules integrated with computational methods and artificial intelligence. Applications included modeling bridges and designing oval stadiums. The afternoon featured a session on *Didactics* which explored geometric models, digital tools, and creative exercises for teaching mathematical concepts to architecture students. Topics included curve tracing, anamorphosis, and complex surfaces. *Perspective and Projection* was the final session of the day. Presentations in this session analyzed theoretical and practical applications of perspective in historical architecture and art, including works by Sebastiano Serlio, Andrea Pozzo, and Masaccio's *Holy Trinity.* A final demonstration showcased how relief perspective and 3D printing are being used to enhance students' spatial understanding.

Day three began with a session on *Surveys and Models*, which centered on applying digital and geometric methods to accurately survey, measure, and model existing historical buildings. These presentations featured highlighted several different digital tools and provided case studies of their use. This was followed by *Urban Design*, which explored the mathematical, geometric, and structural principles in urban planning. The representation of Portuguese cities and the design of adaptive cities were among the examples presented. The afternoon featured a session on *Structures*, which considered the role of mathematics in structural design and construction. The use of a three-dimensional version of the catenary for the construction of a roof and the building of tile vaults were among the examples presented. *Geometric Design* was the final session of the day. These presentations highlighted use of polyhedral forms in several settings including art, housing, and sacred spaces. In keeping with Nexus tradition, the conference organizers hosted a social evening on the third day of the conference. Participants enjoyed a light dinner in the Palladian Museum's garden, followed by a private concert at Palladio's spectacular Teatro Olimpico. Pianists Stefania Redaelli and Maria Grazia Bellocchio performed a four-hands piano concert featuring the *Hungarian Dances* of Johannes Brahms. This lovely evening was one of the highlights of the four-day meeting.

The final morning began with a session on *Reconstruction and Modeling*, where presenters explored the use of geometric and digital tools to analyze both historical architectures, such as the Teatro San Giovanni Crisostomo, and modern works, including those by Giuseppe Samonà. The morning concluded with a session dedicated to PhD researches. This session offered students who are currently enrolled or recently graduated (2023-2025) an invaluable opportunity to present their work and receive feedback from an audience of professional scholars and architects. The conference officially closed with an afternoon tour of Vicenza's architectural treasures, including the Basilica Palladiana, the Church of Santa Corona, and the Civic Art Gallery at Palazzo Chiericati.

Founded by Kim Williams in 1996, the Nexus conference series has long served as a forum for interdisciplinary dialogue. Williams directed the series through 2023. Following her retirement in 2024, the *Nexus Network Journal* was acquired by SpringerNature, which will continue its publication. In 2025, the no-profit association Nexus Architecture and Mathematics APS was founded to coordinate future conferences. The meeting in Vicenza was the first organized by the association. The next meeting is scheduled for the summer of 2027 in Cartagena, Spain.

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The UID Library

The UID Library

edited by Vincenzo Cirillo and Laura Farroni

The UID Library brings together monographs and edited volumes published by its members since 2016 based on voluntary submissions by UID members to the annual call for submissions of scientific publications in the discipline published during that year.
The publications are organized into three main thematic areas: *Theory, practice, and history of drawing*; *Theory, practice, and history of surveying*; and *Theory, practice, and history of multimedia communication*.
All scientific publications by members submitted to the UID Library and published in 2025 are listed below.
Titles addressing topics aligned with the call for papers of the issue are marked with the (•) symbol.
In addition, a selection of titles consistent with the themes of the call for papers of the issue has been drawn from the scientific publications published between 2016 and 2024 and included in the catalogue available on the website of the UID - Unione Italiana per il Disegno (<https://www.unioneitalianadisegno.it/wp/pubblicazioni/>).
For volumes available in Open Access, the link to directly access the text is provided, while for those that refer to the video recording of the presentation of the volume in the scientific review *1 libro: 1 disegno* (<https://www.unioneitalianadisegno.it/wp/2025/11/04/1-libro-1-disegno-22/>), the date and reference link are indicated in square brackets.

Theory, practice, and history of drawing

Monographs

2025

- Buratti, G., Mele, G., Rossi, M. (2025). *"Mirabili artificio". Santa Maria presso San Satiro. Numero e misura nel progetto dello spazio immaginario di Bramante architetto a Milano*. Milano: Biblion edizioni.

Incerti, M. (2025). *Cieli Paleocristiani. Dalla misura alla sua rappresentazione*. Padova: Libreria Universitaria.

- Inglese, C. (2025). *Disegni di Pietra. Le costruzioni geometriche nei tracciati di cantiere*. Roma: Gangemi editore.

- Pirinu, A. (2025). *Forti e cittadelle militari nell'Europa del Cinquecento: Forma, geometria e rappresentazione. Forts and military citadels in the Europe of the sixteenth century. Shape, geometry and representation*. Napoli: La scuola di Pitagora. <https://www.scuoladipitagora.it/_filespdf/TF23-9791256130542.pdf>.

Pirinu, A., Rassu, M. (2025). *L'architettura militare nella Sardegna sabauda. Storia e Disegno di un paesaggio fortificato*. Cagliari: UNICApress. <https://unicapress.unica.it/index.php/unicapress/catalog/view/978-88-3312-194-9/978-88-3312-194-9/978-1>.

- Rossato, L. (2025). *Grade Runner. La reinterpretazione del giocattolo attraverso la rappresentazione digitale*. Rimini: Maggioli Editore.

Ugliotti, F.M. (2025). Greenery. *Il Disegno della Resilienza. La Resilienza del Disegno*. Milano: Pavia University Press. <https://www.paviauniversitypress.it/catalogo/greenery/6712>.

2024

Capone, M. (2024). *Dal piano alla superficie. Strumenti e metodi per costruire forme complesse*. Milano: FrancoAngeli. <https://series.francoangeli.it/index.php/oa/catalog/view/1187/1046/6533>.

Carlevaris, L. (2024). *L'Ottica di Claudio Tolomeo nella storia della prospettiva*. Roma: Edizioni Quasar. <https://www.torrossa.com/en/resources/an/5756664#>.
[5 december 2025 – https://youtu.be/pq8zabY5glg]

Pagliano, A. (2024). *Geometries of anamorphic illusions. Landscape, Architecture, Contemporary art and Design*. Cham: Springer.
[19 december 2025 – https://youtu.be/ahauv5L4O3w]

2023

Agnello, F. (2023). *La memoria fotografica dell'architettura. Restituzioni prospettiche e ricostruzioni*. Milano: FrancoAngeli. <https://series.francoangeli.it/index.php/oa/catalog/view/929/781/5358>.
[26 april 2024 – https://www.youtube.com/watch?v=1F1bAGF09_I]

Mancini, M.F. (2023). *Esordio, maturità e consacrazione internazionale di Andrea Pozzo. Prospettiva e architettura nei grandi cicli di Mondovì, Roma e Vienna*. Torino: Fondazione 1563 per l'Arte e la Cultura della Compagnia di San Paolo. <https://www.fondazione1563.it/pdf/8.2_Mancini-IIIB.pdf>.
[29 november 2024 – https://www.youtube.com/watch?v=w4uCV_fO4og]

2022

Cumino, C., Pavignano, M., Zich, U. (2022). *Geometrie tangibili. Catalogo visuale di modelli per la comprensione della forma architettonica. Tangible geometries. Visual catalogue of models for understanding the architectural shape*. Roma: Aracne.
[23 june 2023 – https://www.youtube.com/watch?v=4-WYmQUftpw]

Migliari, R., Fasolo, M. (2022). *Prospettiva. Teoria e Applicazioni*. Milano: Ulrico Hoepli Editore.
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2021

Ciammaichella, M. (2021). *Scenografia e prospettiva nella Venezia del Cinquecento e Seicento. Premesse e sviluppi del teatro barocco. Scenography and Perspective in Sixteenth and Seventeenth Centuries in Venice Preconditions and Developments of Baroque Theatre*. Napoli: La scuola di Pitagora.
[25 february 2022 – https://www.youtube.com/watch?v=mZn19r3AZzs]

Cirillo, V. (2021). *Feste settecentesche a Napoli. Disegni e progetti per l'architettura effimera. Eighteenth-century celebrations in Naples. Drawings and designs for ephemeral architecture*. Napoli: La scuola di Pitagora. <https://www.scuoladipitagora.it/_filespdf/TF15-9788865428368.pdf>.
[23 september 2022 – https://www.youtube.com/watch?v=S-2hDUOtvlo&t=908s]

Docci, M., Gaiani, M., Maestri, D. (2021). *Scienza del disegno*. Torino: CittàStudiEdizioni.

Valenti, G.M. (2021). *Di segno e Modello*. Roma: FrancoAngeli.
[16 december 2022 – https://www.youtube.com/watch?v=VVyNSkFBXLc]

Williams, K., Monteleone, C. (2021). *Daniele Barbaro's Perspective of 1568*. Cham: Birkhäuser.
[27 may 2022 – https://www.youtube.com/watch?v=OqcTe9Ozux4]

2020

Antuono, G. (2020). *San Carlo alle Quattro Fontane. La dimensione e la forma attraverso la Regola*. Roma: Edizioni Kappa.
[24 september 2021 – https://www.youtube.com/watch?v=r6cXG-agr_g]

Bianchini, C., Calvo-López, J., Giordano, A., López-Mozo, A., Navarro-Camallonga, P., Spallone, R., Vitali, M. (2020). *Sistemi voltati complessi: geometria, disegno, costruzione. Complex Vaulted Systems: Geometry, Design, Construction*. Canterano: Aracne.
[29 october 2021 – https://www.youtube.com/watch?v=A1sxu2ZcrBY&t=1s]

Bortot, A. (2020). *Emmanuel Maignan e Francesco Borromini. Il progetto di una villa scientifica nella Roma barocca*. Siracusa: LetteraVentidue.
[16 july 2021 – https://www.youtube.com/watch?v=dmvJk75hxvc]

Monteleone, C. (2020). *La prospettiva di Daniele Barbaro. Note critiche e trascrizione del manoscritto It. IV, 39=5446*. Canterano: Aracne editrice.
[28 may 2021 – https://www.youtube.com/watch?v=ukIl_MRL8n8&t=6062s]

2019

Bianchi, A. (2019). *Disegnare Oggi, Elementi di Geometria. Drawing Now, Elements of Geometry*. Santarcangelo di Romagna: Maggioli.

Cirillo, V. (2019). *Riflessioni e suggestioni fra geometria e forma. Le scale del '700 napoletano. Reflection and suggestion between geometry and form. The Neapolitan staircases of eighteenth century*. Napoli: La scuola di Pitagora.

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

Lanzara, E. (2019). *Shaping & Paneling. Superfici complesse per l'architettura e il design*. Milano: FrancoAngeli.

2018

Pagliano, A. (2018). *Le ore del sole. Geometria e astronomia negli antichi orologi solari romani*. Napoli: Editori Paparo.

2017

Cardone, V. (2017). *Gaspard Monge padre dell'ingegnere contemporaneo*. Roma: DEI srl Tipografia del Genio Civile.

Liva, G. (2017). *Proiezione e rappresentazione. Una storia millenaria*. Canterano: Aracne.

Spallone, R., Vitali, M. (2017). *Volte stellari e planteriane negli atri barocchi in Torino. Star-shaped and Planterian Vaults in Turin Baroque Atria*. Canterano: Aracne.

Edited volumes

2025

• Balzani, M., Baratin, L., Gasparetto, F., Maietti, F., Raco, F., Rossato, L., Tronconi, V. (a cura di). (2025). *Un Dialogo Possibile: Rappresentare e Conservare il Contemporaneo*. Rimini: Maggioli Editore.

Davico, P. (a cura di). (2025). *Disegnare la città. Caratteri identitari di Borgo Dora*. Torino: Edizioni Politecnico di Torino.

• Farroni, L., Incerti, M., Pagliano, A. (a cura di). (2025). *Attraversare il tempo. Tracce materiali e nuove prospettive*. Padova: Libreria Universitaria.

Farroni, L., Mancini, M.F. (a cura di). (2025). *Ambienti flessibili. Creatività, inclusione, ecologia, reale/virtuale. Teorie e buone pratiche per l'architettura*. Roma: RomaTrE-Press.

2019

De Carlo, L., Paris, L. (a cura di). (2019). *Le linee curve per l'architettura e il design*. Milano: FrancoAngeli. <https://series.francoangeli.it/index.php/oa/catalog/view/409/209/1939>.

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Valenti, G.M. (a cura di). (2016). *Prospettive architettoniche. Conservazione digitale, divulgazione e studio*. Vol. II. Roma: Sapienza Università Editrice. <https://books.google.it/books?id=YHSSDwAAQBAJ&printsec=frontcover&hl=it&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false>.

Theory, practice, and history of surveying

Monographs

2025

- Cicala, M. (2025). *Approcci sistemici per la conoscenza e la valorizzazione delle architetture snelle. Campanili contemporanei a Napoli. Systemic Approaches to the Knowledge and Enhancement of Slender Architecture. Contemporary bell towers in Naples*. Napoli: La scuola di Pitagora editrice. <https://www.scuoladipitagora.it/_filespdf/TF24-9791256130702.pdf>.

Edited volumes

2025

Fatta, F., Mediati, D. (a cura di). (2025). *Il Museo archeologico regionale eoliano "Luigi Bernabò Brea". La fruizione del patrimonio culturale*. Roma: Carocci editore.

Theory, practice, and history of multimedia communication

Monographs

2025

Bevilacqua, M., Bonfitto, M., Davico, P., Minucciani, V. (2025). *Per non dimenticare. Voci del dramma nell'ex Manicomio di Collegno*. Roma: WriteUp.

D'Alessio, M. (2025). *Narrazioni Immersive. Scenari virtuali per la valorizzazione del patrimonio culturale*. Alghero: Publica Editore. <https://publicapress.it/wp-content/uploads/2025/10/NARRAZIONI%20IMMERSIVE%20-%20MIRCO%20DALESSIO%20v2.pdf>.

Meloni, A. (2025). *Percepire e rappresentare lo spazio oltre la visione. Strategie di comunicazione multisensoriale per l'accessibilità del Museo di Arte Orientale Edoardo Chiossone*. Napoli: FedOA. <http://www.fedoabooks.unina.it/index.php/fedoapress/catalog/view/653/687/3250>.

Edited volumes

2025

Sias, A. La Vitola, N., Mollica, S., Camagni, F., Martelli, L., Mercurio, S., Wilches Rivera, J.S., Sanna, S., Vespasiano, L., Benitez Calle, A. (a cura di). (2025). *GRAF_I. La rappresentazione per la narrazione della cultura immateriale*. Alghero: Publica Press. <https://publicapress.it/wp-content/uploads/2025/07/Graf_I_2024.pdf>.

UID Awards 2025

UID Gold Plaques 2025

committee: Francesca Fatta, Carlo Bianchini, Paolo Giandebiaggi

UID Gold Plaque 2025 to Ornella Zerlenga

The 2025 Gold Plaque is awarded to Ornella Zerlenga, a scholar whose scientific curriculum is extraordinarily rich in achievements and recognitions.
She received her PhD in 1994, became University Researcher in 2000, Associate Professor in 2001, and Full Professor in 2011 in the disciplinary sector of Drawing at the University of Campania "Luigi Vanvitelli".
She has served as President of the degree programme for both the Bachelor's programmes and the single-cycle Master's programme, and as coordinator of PhD programmes. Since 2020 she has been Director of the Department of Architecture; this role is complemented by numerous other institutional responsibilities within the University, including membership of the Academic Senate.
Her scientific interests originate from a solid background in Geometry and have directed her research both towards the interpretation of architectural artefacts and the built environment and towards conscious and responsible design creativity in the fields of architecture and design.
During her scientific career she has received several awards: in 1989 the 'Luigi Vagnetti' Prize promoted by the Unione Italiana per il Disegno; in 1992 the first prize in the 'Storia del Disegno di Architettura' competition promoted by the scientific journal *XY*; and in 2008 the UID Silver Plaque.
She is Scientific Coordinator of PRIN research projects and competitive university research projects, and coordinator of research groups working on the themes of knowledge, enhancement and digital communication of cultural heritage. Since 2013 she has been a member of the Technical-Scientific Committee of the Unione Italiana per il Disegno, serving in recent years as Treasurer. In November 2024 she was elected President of the scientific society for the three-year term 2024-2027.

UID Gold Plaque 2025 to Guendalina Salimei

Guendalina Salimei stands out in the national and international context for her original and continuous contribution to the field of Drawing, understood as a foundational language of architecture and a critical instrument for design. Her academic activity has innovated teaching by integrating freehand drawing with digital technologies, educating generations of students capable of reading, interpreting and transforming architectural space.

At the same time, as a designer she has placed Drawing at the centre of professional practice, translating it into emblematic works of urban regeneration and renewed collective identity, including the restoration and redevelopment of Corviale in Rome. At both national and international levels, projects such as the Dao Viet Eco City masterplan in Vietnam, the regeneration plan for Bagnoli, the intervention for the Egyptian Museum in Turin, and the multifunctional service centre on the waterfront of Taranto testify to her ability to combine experimentation and social responsibility in diverse and complex contexts.
The culmination of this trajectory is the curatorship of the Italian Pavilion at the 2025 Architecture Biennale (*TERRÆ AQUÆ. Italy and the Intelligence of the Sea*), an extraordinary collective exhibition device reflecting on the collective intelligence required to address the challenges of territories situated at the interface between land and sea.
With coherence and vision, Guendalina Salimei has made Drawing not only a tool of representation but also an inclusive, ethical and regenerative practice, fully aligned with the founding values of the Unione Italiana per il Disegno, which for these reasons has decided to award her the UID Gold Plaque 2025.

UID Gold Plaque 2025 to Laura De Carlo

The UID Gold Plaque 2025 recognises the scientific, teaching and institutional quality of a figure who, with particular passion, rigorous dedication and natural inclination, has investigated and disseminated the principles, methods and applications of Drawing within our community.
She is a figure often associated, in the minds of many, with the contribution she has offered to the renewal of Descriptive Geometry, yet she has also significantly addressed many other aspects of our disciplines, combining a scientific outlook with a remarkable analytical capacity.
From investigations into minor historic centres to urban transformations, she has also addressed contemporary issues, such as those related to the description of urban greenery and landscape.
Always maintaining an attitude oriented towards constructive engagement and openness to the real needs of the contexts in which she has worked, she has never spared her commitment to the Department and the Faculty, serving in various roles. Among these, we must recall her profound interest in third-level education, demonstrated by her significant and continuous commitment within the PhD programme and the National Doctoral School, whose results remain evident today.
Her contribution to the journal *Disegnare. Idee, immagini* has been particularly active and fertile, a journal that would still find it difficult to do without her remarkable ability to anticipate outcomes and configurations. She is therefore a figure who has fostered competencies and nourished scientific collaborations based on sincere esteem and generosity – an example that we now recognise as a living legacy for our community.
For all these reasons, the UID Gold Plaque 2025 is awarded to Laura De Carlo.

Gaspare De Fiore Awards and Mentions 2025
committee: Marcello Balzani, Alessandro Luigini, Cettina Santagati

The Gaspare De Fiore Award 2025 is conferred on Dr Felice Romano, for his PhD thesis in Architecture, Arts and Planning (XXXIV cycle) entitled *Jean-Jacques Lequeu. Il disegno di un enigma architettonico* [Jean-Jacques Lequeu. The Drawing of an Architectural Enigma], defended on 28 June 2024 at the Department of Architecture of the University of Palermo (supervisor Prof. Francesco Maggio, Department of Architecture, University of Palermo; co-supervisor Prof. Edoardo Dotto, Department of Civil Engineering and Architecture, University of Catania), with the following motivation: for the originality and significance of a study that brings renewed attention to Jean-Jacques Lequeu, a figure less well known than his impact would warrant, highlighting his role within the panorama of architectural representation; for the breadth and depth of the investigation, which extends from the corpus of drawings to biography, the analysis of his library, and the historical and cultural context; for the solidity of its methodological framework and the refinement of its critical analysis, capable of offering a significant contribution to scholarship and opening new and fruitful research perspectives.

The Gaspare De Fiore Award 2025 is conferred on Dr Noemi Tomasella, for her International Innovative PhD thesis in History, Drawing and Restoration of Architecture (XXXVII cycle) entitled *Misure dello sguardo. Modelli visuali tra accessibilità e comunicazione* [Measures of the Gaze. Visual Models between Accessibility and Communication], defended on 30 January 2025 at the Department of History, Drawing and Restoration of Architecture of Sapienza University of Rome (supervisors Prof. Elena Ippoliti, Prof. Andrea Casale and Prof. Graziano Mario Valenti), with the following motivation: for the originality of the topic and the fully interdisciplinary approach, intertwining the knowledge of Drawing with that of neuroscience, aesthetics and psychology; for the methodological robustness and the coherence of the experimental framework, characterised by the precise definition of metrics and tools for measuring perceptual phenomena – from eye-tracking to the evaluation of cognitive processes; for the significant contribution to the discipline of Drawing and for opening a promising line of research, destined to have relevant implications for understanding the relationship between observer and image in both real and virtual contexts.

The Gaspare De Fiore Mention 2025 is awarded to Dr Annalisa Brancasi, for her International Innovative PhD thesis in History, Drawing and Restoration of Architecture (XXXVII cycle) entitled *Dal documento iconografico all'esperienza multimediale. Rievocazione del Ninfeo di Villa Giulia prima dei restauri del Settecento* [From the Iconographic Document to the Multimedia Experience. Re-evoking the Nymphaeum of Villa Giulia before the Eighteenth-Century Restorations], defended on 30 January 2025 at the Department of History, Drawing and Restoration of Architecture of Sapienza University of Rome (supervisors Prof. Laura Carlevaris and Dr Jessica Romor; co-tutor Dr Donato Maniello, Glowarp Studio), with the following motivation: for the accomplished integration between the rigour of historical study and digital innovation, which provides the doctoral work with solid foundations for the analysis of architectural heritage while at the same time envisioning applications of great impact in the representation of architecture through spatial augmented reality technologies; for the attention devoted to the enhancement of the historical drawings of Gilles-Marie Oppenord, which become a privileged instrument for interpreting and communicating the value of the heritage assets investigated.

The Gaspare De Fiore Mention 2025 is awarded to Dr Giulia Lazzaretto, for her PhD thesis in Architecture, City and Design, Composition area, Representation curriculum (XXXVI cycle) entitled *Zaha Hadid. Painting in an expanded field. Sul processo creativo e sulla rappresentazione nell'opera di Zaha Hadid* [Zaha Hadid. Painting in an Expanded Field. On the Creative Process and Representation in the Work of Zaha Hadid], defended on 26 September 2024 at Iuav University of Venice (supervisor Prof. Agostino De Rosa), with the following motivation: for the skilful analysis of Zaha Hadid's creative process through her project drawings, capable of shaping a radically innovative visual and spatial language and recognising the centrality of the study of design representation within our disciplinary field; for the perceptive investigation of the synthesis between Middle Eastern cultural heritage and the influence of the Russian avant-gardes, which enabled Hadid to explore a non-Euclidean and dynamic perception of space; and for the valuable contribution to understanding an architecture that, through fragmentation and cinematic dynamics, was able to prefigure new horizons and challenge the conventions of representation.

The Gaspare De Fiore Mention 2025 is awarded to Dr Fabrizio Natta, for his PhD thesis in Architectural and Landscape Heritage (XXXVI cycle) entitled *Modellazione computazionale per l'interpretazione geometrica di sistemi voltati complessi fra teoria e realizzazione* [Computational Modelling for the Geometric Interpretation of Complex Vault Systems between Theory and Construction], defended on 22 July 2024 at the Department of Architecture and Design of the Polytechnic University of Turin (supervisors Prof. Roberta Spallone, Politecnico di Torino, and Prof. Pablo Rodríguez-Navarro, Universitat Politècnica de València), with the following motivation: for the methodological rigour of the research on the computational modelling of complex vault systems; for having masterfully investigated the relationship between geometric theory and architectural practice in the late Piedmontese Baroque; for having offered an innovative systematisation of vaulted structures through the use of advanced digital techniques; and for having developed a flexible and scalable methodology crucial for the understanding and conservation of architectural heritage.