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REFRAMING DESCRIPTIVE GEOMETRY IN THE DIGITAL ERA

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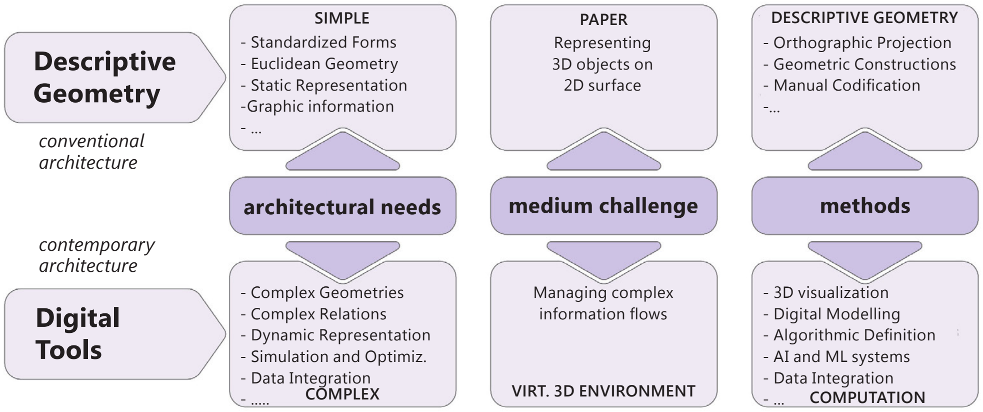
The relationship between descriptive geometry and architecture is undergoing a significant transformation, driven by both the increasing complexity of contemporary architectural demands and the evolution of digital tools. Each technological era – from traditional descriptive geometry through 2D CAD, 3D modelling, computational design, to emerging AI approaches – has fundamentally altered the way geometry is accessed, conceptualised, and manipulated. These transformations have led to the development of new cognitive frameworks for spatial thinking. This article examines this transformation through two complementary analyses. First, it investigates how different technological eras have redefined the medium through which architects engage with geometry, focusing on how these shifts in medium have transformed cognitive mechanisms from projection-based reasoning to algorithm-based thinking and, more recently, to natural language interaction. Second, the article identifies descriptive geometry's evolving roles in contemporary architectural practice, research, and education, revealing both invariant principles that persist regardless of technological mediums and new geometric competencies required by contemporary architectural challenges. The analysis demonstrates that descriptive geometry represents not a fixed operational methodology but an evolving framework for spatial reasoning that transcends specific technological implementations. This contributes to the ongoing dialogue about geometric literacy in the computational age.

Keywords: *Descriptive Geometry, Architecture, Graphic Expression, Geometric Thinking, Digital Tools.*

Descriptive Geometry at the Crossroads of Architectural Evolution

Architecture practitioners had been employing projection techniques to solve spatial problems long before Monge's systematization[1]. The historical evolution of these methods reflects architecture's continuous negotiation with available media, where descriptive geometry methods evolved in response to changing conceptualizations of space across architectural history[2]. Descriptive geometry thus represents a continuous trajectory of geometric thinking that extends beyond Monge's formalization[3]. Monge himself acknowledged this historical continuity while articulating the discipline's dual objective: to establish methods for representing three-dimensional bodies on two-dimensional surfaces and to deduce spatial truths from these exact constructions[4] . This formulation reveals two pervasive features of any geometric tool that significantly influence architectural practice: the representational medium (paper in descriptive geometry) and the methods developed specifically to overcome the inherent limitations of that medium. This interdependence between medium and method constitutes a fundamental dynamic in the evolution of architectural representation and thinking. This relationship not only highlights the adaptability of geometric tools but also emphasizes their role in shaping the theoretical and practical frameworks of architectural design. Contemporary architecture faces challenges of unprecedented complexity – including sustainability imperatives, urban metabolism optimization, performance-based design requirements, and digital fabrication – that redefine the geometric problems architects must address[5]. The technological paradigm has shifted from representational systems attempting to overcome two-dimensional limitations to compu-

1 Taton, *L'œuvre scientifique de Monge.*
2 Evans, *The projective cast: architecture and its three geometries;* Pérez-gómez, *Questions of representation: the poetic origin of architecture*, pp. 217-225.
3 Migliari, *Descriptive Geometry: From its Past to its Future*, pp. 555-571.
4 Monge, *Géométrie Descriptive - Leçons données aux Écoles normales, l'An 3 de la République.*
5 Cfr. Carl, *Urban Density and Block Metabolism*, p. 852; Hensel, *Data-driven design for Architecture and Environment Integration Convergence of data-integrated workflows for understanding and designing environments.*



1 | *Architectural needs, medium challenges, and methods. Contrasts between conventional architecture (Descriptive Geometry) versus contemporary architecture (Digital Tools).*

"Descriptive geometry's transformation across technological eras, analysing how different media redefine both geometric tools and architectural thinking.

tational environments where geometry is directly manipulated, analysed, and optimised in a virtual three-dimensional space[6]. This transformation raises critical questions about the contemporary relevance of descriptive geometry, as its foundational premise has been technologically redefined[7] (fig. 1). This article examines descriptive geometry's transformation across technological eras, analysing how different media redefine both geometric tools and architectural thinking. The evolution from 2D drafting through 3D modelling to algorithmic design and emerging AI applications has progressively abstracted geometry from direct manipulation, creating new conceptual frameworks for spatial thinking[8]. Through examination of scientific literature and contemporary practice, we identify both persistent principles that transcend technological shifts and the new geometric competencies required by current architectural demands.

The Evolution of the Medium: How Technology Reshapes Geometric Tools and Thinking

The medium through which architects engage with geometry plays a fundamental role in shaping both conceptual frameworks and design methodologies. Each technological transition – from manual drafting to computational design and, more recently, AI-assisted processes – reconfigures the cognitive, operational, and epistemological dimensions of geometric practice. This section examines these technological transitions not merely as instrumental developments but as paradigmatic shifts that reshape how architects conceptualize, operate, and even manage geometric information. The analysis foregrounds the reciprocal relationship between representational media and architectural thinking, demonstrating how each technological medium simultaneously enables new geometric possibilities while imposing specific constraints and conceptual frameworks that shape architectural cognition and practice[9].

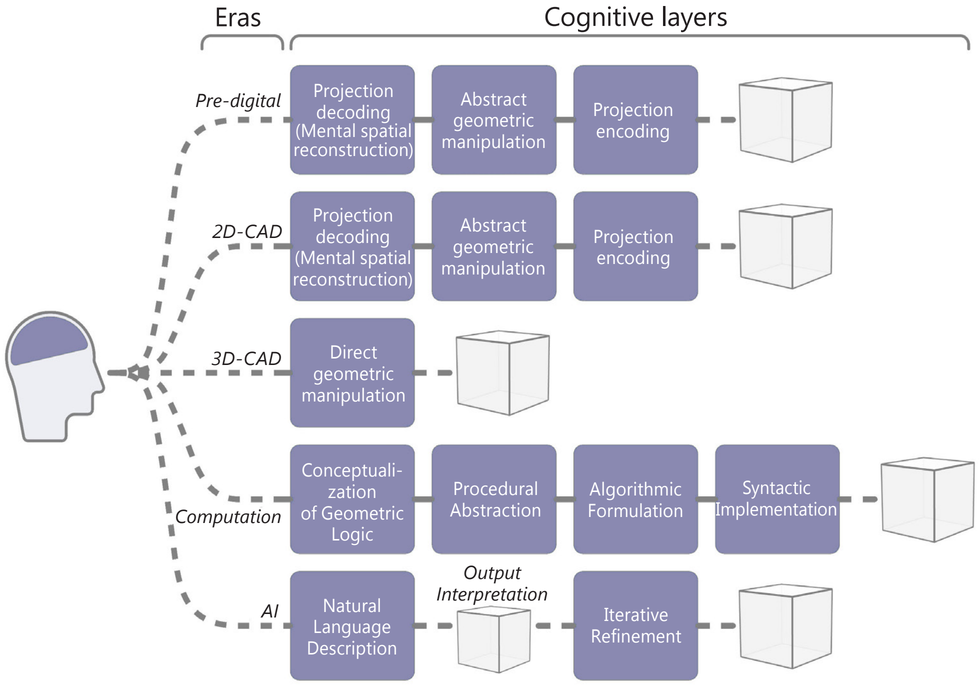
Pre-Digital Era: Projection as Conceptual Framework

The pre-digital era of architectural geometry was characterised by a fundamental cognitive framework predicated on projection, both as a technical procedure and as a conceptual apparatus. This projection-based conceptual framework necessitated sophisticated mental operations of spatial visualization, requiring architects to engage in multiple cognitive processes of a continuous cycle of mental codification and decodification between two-dimensional representations and three-dimensional spatial concepts for each geometric operation[10].
This translation process's cognitive load shaped architectural practice through analytical decomposition and sequential reasoning[11], establishing an epistemological distance between cognitive processes and architectural objects[12]. Architects necessarily operated in a reflective conversation through mediated representational systems, creating geometric reasoning modes bound to projection-based techniques' constraints and affordances[13].

2D CAD Era: The first digital transition

The transition to 2D CAD systems represented a nuanced technological evolution in architectural representation. While fundamentally preserving the cognitive process of translating between two-dimensional and three-dimensional conceptions, these systems introduced critical advancements. Early CAD implementations primarily functioned as digital analog to traditional drafting prac-

6 Johnson, *Sketchpad III. Three-Dimensional Graphical Communication with a Digital Computer.*
7 Carpo, *The Digital Turn in Architecture 1992-2012.*
8 Carpo, *The Second Digital Turn: Design beyond Intelligence;* Menges & Ahlquist, *Computational Design Thinking: Computation Design Thinking.*
9 Cfr. Oxman, *Theory and design in the first digital age*, pp. 229-265.
10 Akin et al., *Problem structuring in architectural design.*
11 Akin, *Psychology of Architectural Design.*
12 Oxman, *The thinking eye: visual re-cognition in design emergence*, pp. 135-164
13 Evans, *The projective cast: architecture and its three geometries*, cit.



2 | *Cognitive layers across technological eras: how architects access and manipulate geometric objects. More layers represent a greater epistemological distance between the architect's mind and geometry, with the 3D modelling era providing the most direct access.*

tices, replicating established representational conventions[14], and maintaining the existing epistemological distance while altering their material substrate.

Critically, 2D CAD systems significantly enhanced geometric practice through increased precision, productivity and manipulability, allowing new constructions beyond straight edge and compass limitations[15]. These capabilities subtly reconfigured representation and conception, expanding geometric possibilities while preserving fundamental projection-based cognitive frameworks[16].

3D Modeling Era: Liberation from projection as a conceptual device

The emergence of 3D modelling systems marked a fundamental epistemological shift in architectural geometry, radically transforming the relationship between conception and representation. Unlike previous paradigms that required constructing three-dimensional understanding from two-dimensional projections, 3D modelling established a digital environment for direct spatial manipulation of geometry, eliminating the traditional codification-decodification cycle, introducing a new cognitive framework and reducing the epistemological distance between conception and representation[17].

This approach facilitated novel explorations of geometric complexity[18], and provided a continuous spatial reasoning approach that fundamentally altered architectural thinking[19]. Building Information Modeling (BIM) further expanded this transformation, converting geometric models from mere representations to comprehensive information systems that connect conceptualization, analysis, and fabrication through integrated digital structures[20].

Computational Design Era: From objects to processes

The Computational Design Era marks a fundamental shift from the direct manipulation of geometric objects in 3D virtual environments (computerization) to the automation of design tasks through algorithmic processes (computation)[21]. Architects now articulate rule-based systems that generate geometry rather than directly manipulating form.

This transition establishes algorithms as a new cognitive medium, introducing a representational language rooted in programming[22]. This shift demands an unprecedented level of abstraction and rationalization in architectural thinking. Designers must engage with geometry through multiple layers: from direct manipulation to parametric relationships to algorithmic processes[23]. The practice transforms from visually-mediated to one increasingly governed by mathematical and algorithmic formulations[24] (fig. 2).

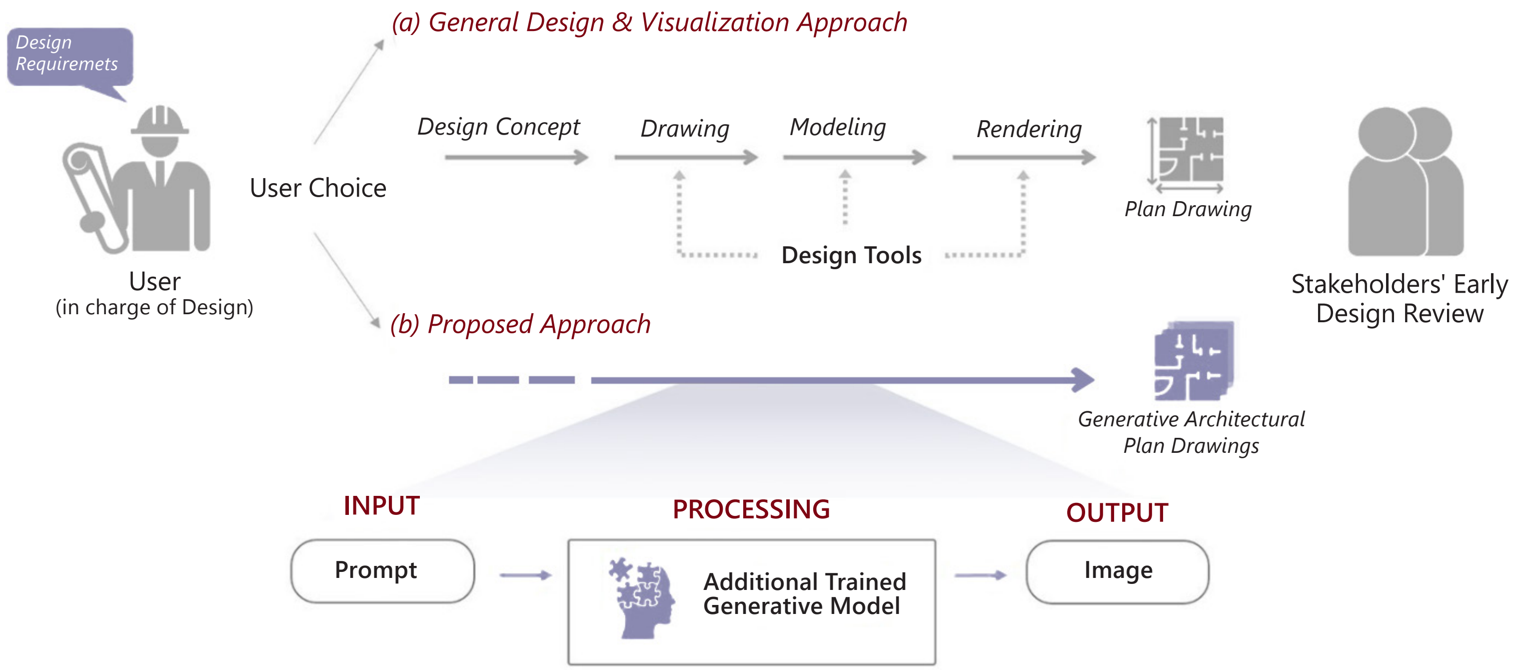
This transformation establishes a cognitive framework of procedural thinking and mathematical formalism. Paradoxically, while reducing the distance between conception and geometric outcome – both virtual and physical – it increases the epistemological distance through greater levels of abstraction in accessing geometric potentialities[25].

Emerging AI Era: From explicit to implicit geometric definition

The integration of artificial intelligence into architectural design marks another fundamental epistemological transformation in geometric operation. This paradigm shift reconfigures the cognitive medium through which geometry is accessed, transitioning from explicit algorithmic definition to implicit generation through machine learning systems.

AI introduces a natural language interface to geometric manipulation[26], allowing communication with geometry through descriptive terms rather than formal mathematical articulations in an abstract programming language.

14 Bhavnani et al., *CAD usage in an architectural office: From observations to active assistance*, pp. 243-255.
15 Barrera-Vera, *Elicon*.
16 Eastman, *Architectural CAD: a ten year assessment of the state of the art*, pp. 289-292.
17 Kolarevic, *Architecture in the Digital Age: Design and Manufacturing*.
18 Aish & Noakes, *Architecture without numbers–CAAD based on a 3D modelling system*, pp. 321-328.
19 Woodbury, *Strategies for Interactive Design Systems*.
20 Eastman, *Building Product Models: Computer Environments, Supporting Design and Construction*.
21 Cfr. Terzidis, *Algorithmic Architecture*.
22 Aish, *DesignScript: Scalable Tools for Design Computation*, pp. 87-95; Aish, *First Build Your Tools*, pp. 39-49.
23 Woodbury, *Elements of Parametric Design*.
24 Menges & Ahlquist, *Computational Design Thinking: Computation Design Thinking*, cit.
25 Oxman, *Thinking difference: Theories and models of parametric design thinking*.



3 | *General design and visualization approach and generative approach according to Dai Shuyao.*

This transformation alters the epistemological structure of geometric practice by positioning machine cognition as an interpretive intermediary between designer intention and geometric manifestation, establishing a collaboration between human intent and machine interpretation[27].

AI systems again reduce the epistemological distance through intuitive interfaces[28], Geometric knowledge must now be reformulated through linguistic strategies rather than direct geometric specification. This reconfiguration transforms architectural geometric cognition into a distributed cognitive system where expertise is negotiated between human and machine intelligence through iterative processes of prompt formulation, generation, and evaluation[29]

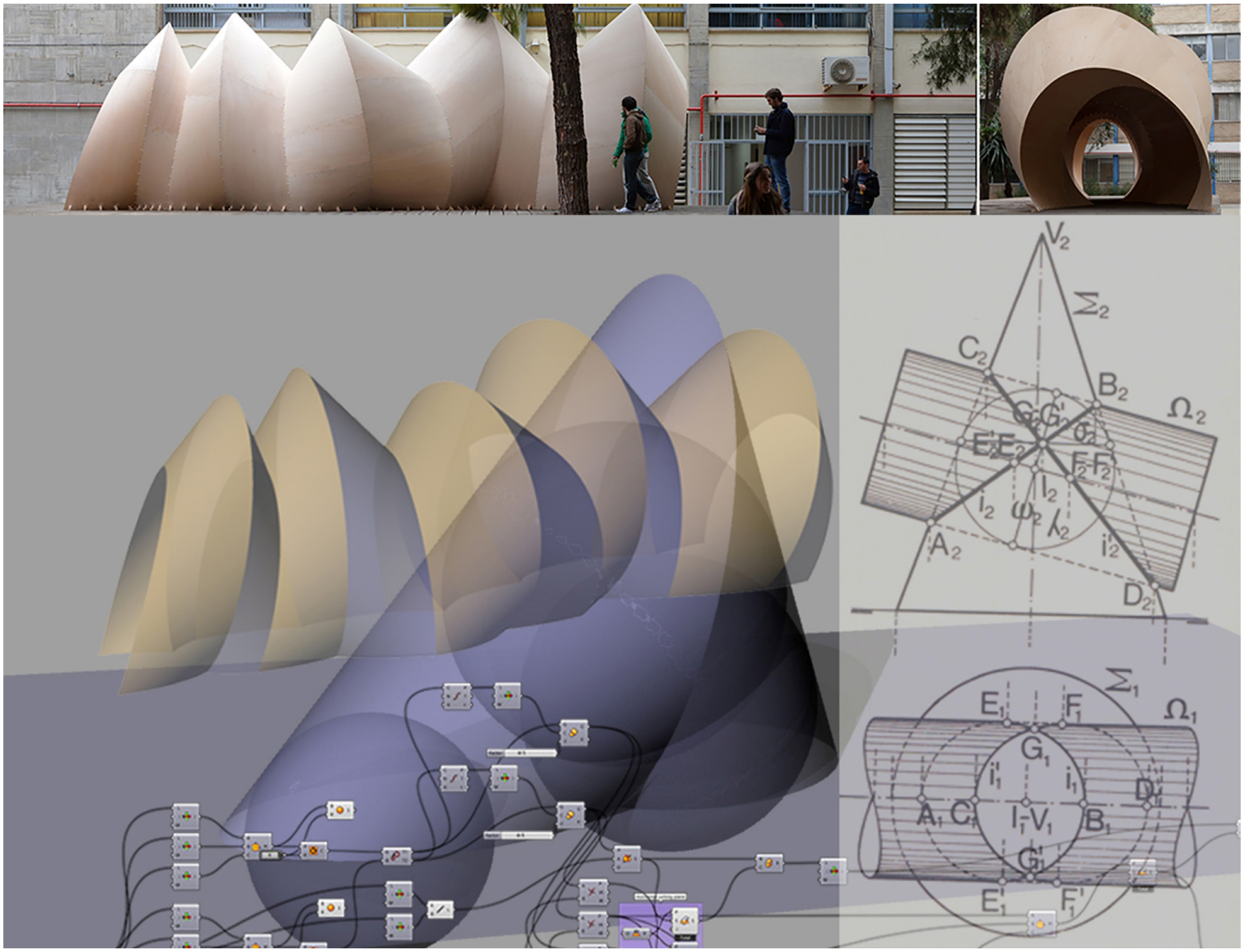
The New Roles of Descriptive Geometry in Contemporary Architecture

The previous persistent negotiation between technological disruption and disciplinary continuity establishes a theoretical framework for examining descriptive geometry's contemporary roles. This analysis necessitates differentiation between three interconnected domains; practice, research, and education, as each engages with geometric principles through distinct epistemological frameworks, operational contexts, and developmental trajectories, revealing uniqueaspects of descriptive geometry's evolving relevance. By analysing descriptive geometry's relationship to contemporary architectural challenges through this tripartite structure, we can identify both the enduring conceptual foundations that transcend particular technological implementations and the emergent geometric competencies necessitated by contemporary architectural demands.

In Architectural Practice: From direct application to conceptual foundation

The direct application of traditional descriptive geometry methods has often become obsolete in professional workflows, primarily due to inherent limitations in its mediating apparatus. Examining Monge's original objectives – representation and analysis of three-dimensional forms – reveals significant shortcomings when applied to contemporary architectural demands. The representational function of descriptive geometry has been effectively superseded by three-dimensional digital environments that eliminate the need for codification-decodification processes between dimensions. For instance, Building Information Modeling frameworks establish geometric consistency across representations while simultaneously integrating non-geometric data attributes that traditional projective methods cannot accommodate[30].

26 Li et al., *Generative AI for Architectural Design: A Literature Review*, pp. 1-32.
27 Weber et al., *Designing successful Human-AI Collaboration for Creative-Problem Solving in Architectural Design.*
28 Choi et al., *Generative architectural plan drawings for early design decisions: data grounding and additional training for specific use cases.*
29 Shuyao et al., *Towards Human-AI Collaborative Architectural Concept Design via Semantic AI*, pp. 68-82.



4 | *Photographs of The Caterpillar Gallery. Bottom: images of the algorithmic design process in Grasshopper for Rhinoceros 3D and the representation, in one single multiview orthography projection, of two classic Descriptive Geometry theorems applied in the project.*

Similarly, the analytical function, deducing spatial truths through geometric construction, has been transformed through computational analysis tools that provide quantitative assessment across multiple performance criteria simultaneously[31]. Despite this technological supersession, fundamental geometric reasoning persists as an essential conceptual foundation within computational workflows. Traditional geometric operations have been transformed rather than abandoned; intersections, developments, and projection operations remain fundamental components within computational processes, albeit reconceptualised through digital processes[32]. This transformation represents an operational continuity through technological disruption, where established geometric literacy remains essential while its implementing mechanisms are radically reconfigured[33] evolving towards a computational geometric reasoning where traditional principles inform algorithmic processes within digital environments[34].

However, projection-based representations maintain limited yet significant roles in contemporary practice, primarily in two contexts: (1) documentation of existing conditions where historical plans constitute primary information sources, particularly in heritage-related projects[35]; and (2) regulatory compliance processes requiring standardised orthographic documentation. These contexts necessitate bidirectional exchange between digital systems and projection-based representations, creating hybrid geometric workflows where practitioners must systematically translate between computational models and conventional projection methods to navigate practical, legal, and historical constraints[36].

30 Schiavi et al., *BIM data flow architecture with AR/VR technologies: Use cases in architecture, engineering and construction.*
31 Oxman, *Digital architecture as a challenge for design pedagogy: theory, knowledge, models and medium*, pp. 99-120.
32 Pottmann et al., *Architectural geometry*, pp. 145-164.
33 Kolarevic, *Architecture in the Digital Age: Design and Manufacturing*, cit.
34 Peters, *Computation works: The building of algorithmic thought.*
35 Martinez-Moya, *Metodología de recuperación gráfica de las portadas del Palacio Condal de Oliva.*
36 Kernighan, *Extracting geometric information from architectural drawings.*
37 Gonzalez Quintial, Martin Pastor, *Monge Surfaces. Generation, Discretisation and Application in Architecture.*

In Architectural Research:
New frontiers for geometric exploration

Within architectural research contexts, descriptive geometry has undergone significant conceptual expansion beyond its traditional operational applications. Contemporary scholarship reveals at least three distinct trajectories where descriptive geometry principles remain instrumental despite technological transformation.

Historical architectural research represents the first trajectory, where researchers investigating primary historical documents – stereotomy and masonry treatises, architectural manuscripts, construction manuals, or builders' drawings – must necessarily develop expertise in period-specific descriptive geometry methodologies to extract meaningful insights. The interpretation of these historical documents requires operational fluency with projection-based representational systems that governed architectural conception and materialisation during their respective periods.

Computational reinterpretation of classical descriptive geometry principles constitutes a second significant trajectory in contemporary research. Through algorithmic reformulation of traditional theorems and principles, the following examples demonstrate the enduring relevance of these principles within computational design frameworks[37]. The Caterpillar Gallery (fig.4), which implements Monge's theorem on quadric surfaces to generate complex spatial configurations through developable conical surfaces[38]; and The Archimedean Pavilion (fig. 5), which employs a projective interpretation of Archimedes' theorem to enable the discretization of parabolic domes[39].

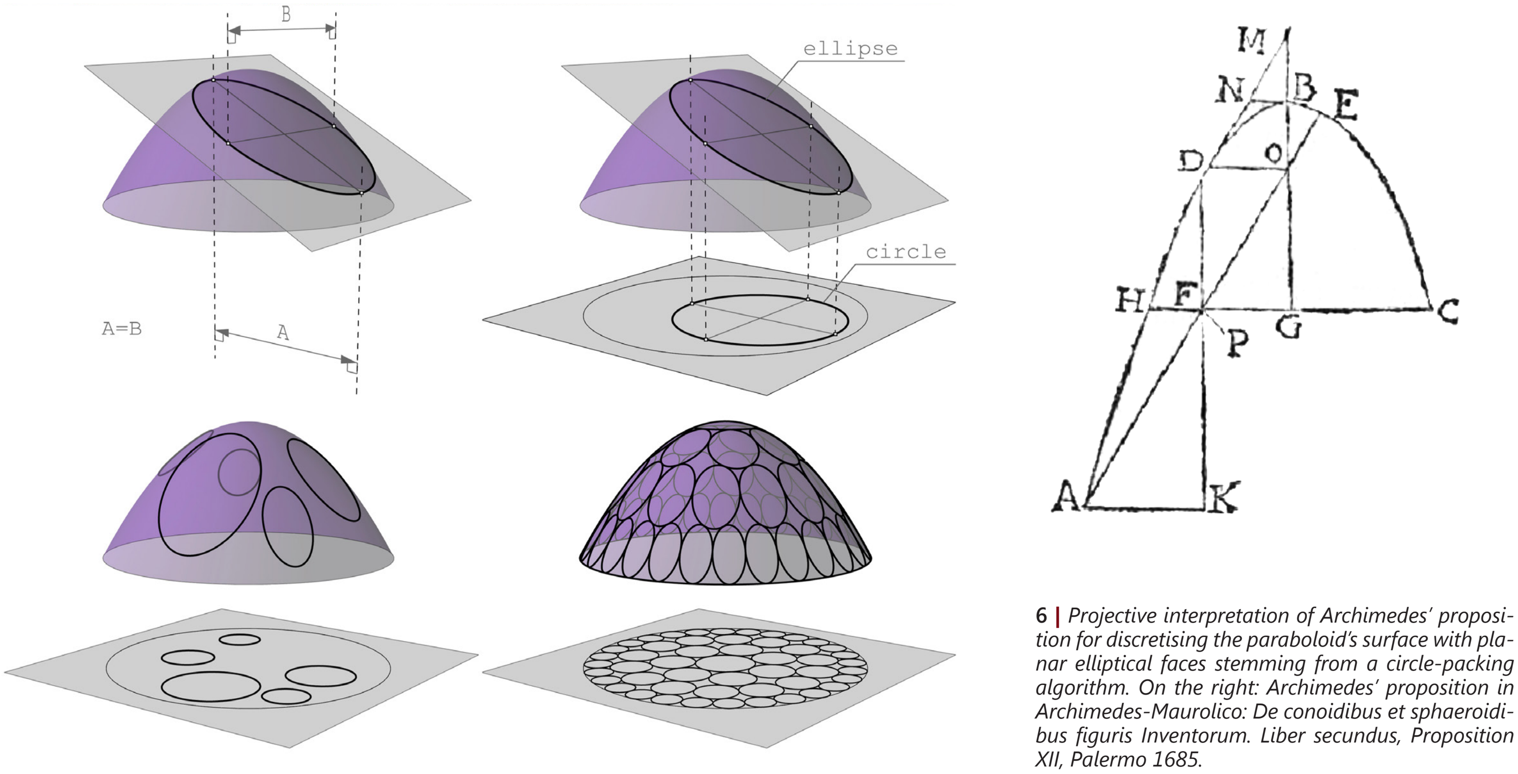
These cases demonstrate how the role of geometric reasoning in computational workflows and geometrically-informed algorithms significantly optimize computational processes by leveraging two-dimensional projective properties to define three-dimensional complex forms, thereby reducing algorithmic complexity while simultaneously enhancing structural performance, material efficiency, and fabrication feasibility within contemporary architectural production.The third trajectory, although representing relatively isolated occurrences within the broader literature, demonstrates the remarkable adaptability of descriptive geometry principles across diverse research domains beyond conventional architectural applications. This interdisciplinary expansion includes innovative "reverse descriptive geometry" methodology, which reconstructs 3D masonry structures from 2D images; application of high-dimensional descriptive geometry to neural network pattern recognition systems; and theoretical framework of "Generalised Descriptive Geometry" (GDG) for constructively imaging abstract mathematical objects through algorithmic translations[40].

5 | *Photographs of The Archimedean Pavilion.*

38 Narvaez-Rodriguez, Martin-Pastor, *From Descriptive Geometry to Architectural Geometry: Contributions by Classic Authors to the New Paradigm*.

39 Cfr. Narváez-Rodríguez et al., *Lightweight Conical Components for Rotational Parabolic Domes: Geometric Definition, Structural Behaviour, Optimisation and Digital Fabrication*, pp. 378-397; Martín-Pastor, Narvaez-Rodriguez. *New Properties About the Intersection of Rotational Quadratic Surfaces and Their Applications in Architecture;* Narváez-Rodríguez et al., *Lightweight Conical Components for Rotational Parabolic Domes: Geometric Definition, Structural Behaviour, Optimisation and Digital Fabrication* cit., pp. 378-397.

40 Schreiber, *Generalized Descriptive Geometry.*



6 | *Projective interpretation of Archimedes' proposition for discretising the paraboloid's surface with planar elliptical faces stemming from a circle-packing algorithm. On the right: Archimedes' proposition in Archimedes-Maurolico: De conoidibus et sphaeroidibus figuris Inventorum. Liber secundus, Proposition XII, Palermo 1685.*

In Architectural Education: New Competences for New Demands
Contemporary architectural education must negotiate the complex interface between enduring geometric principles and rapidly evolving technological paradigms. Analysis of the fundamental epistemological transformations documented in previous sections could reveal three essential competency clusters for geometric education in the computational era:

- First, students require proficiency in Creating Geometric Models, Simulations and Algorithmic Definitions in Digital Environments, encompassing the construction of basic geometric elements, analysis of interactions between them, generation of composite objects, application of transformations, modeling of complex surfaces with embedded fabrication parameters, and extraction of geometric information from complex assemblies. This competency cluster adapts traditional descriptive geometry operations to computational frameworks while maintaining conceptual continuity.
- Second, and most critically for future practice as the competencies in the first cluster become increasingly automated by artificial intelligence systems, students must develop capabilities for Managing Flows of Information Between Physical and Digital Environments. This emergent competency domain involves understanding and translating geometric information across diverse representational systems, evaluating fabrication processes, and effectively communicating geometric information through multiple platforms, including human and artificial intelligence interactions. This cluster represents a fundamental evolution beyond traditional descriptive geometry, addressing the increasingly permeable boundary between digital conception and physical materialization.
- Third, students continue to require competency in Interpreting and Generating Orthographic Projections with Precision, though now contextualised within computational workflows. This maintains connection with historical representational conventions while acknowledging their reconfigured role within contemporary practice.

Conclusion: Towards a New Understanding of Descriptive Geometry

This analysis reveals that descriptive geometry's transformation across technological eras represents neither obsolescence nor unchanged continuity, but rather a fundamental reconceptualization of its principles within evolving architectural paradigms. The persistent cognitive operations of descriptive geometry – spatial visualization, geometric reasoning, and analytical decomposition – remain essential, even as their implementing mechanisms evolve from projection-based systems to computational frameworks. Contemporary practice demonstrates that while traditional applications have diminished, the underlying conceptual foundations inform emerging computational methodologies across practice, research, and education.

This reconceptualization necessitates redefining descriptive geometry not as a fixed operational methodology, but as an evolving framework for spatial reasoning that transcends particular technological implementations. Future research should further examine how geometric competencies transfer across technological transitions, particularly as AI systems introduce new cognitive interfaces to geometric operation. Ultimately, descriptive geometry's enduring relevance lies not in its historical techniques but in its conceptual apparatus for navigating the increasingly complex relationship between architectural conception and materialization.

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