

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. NLP (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,

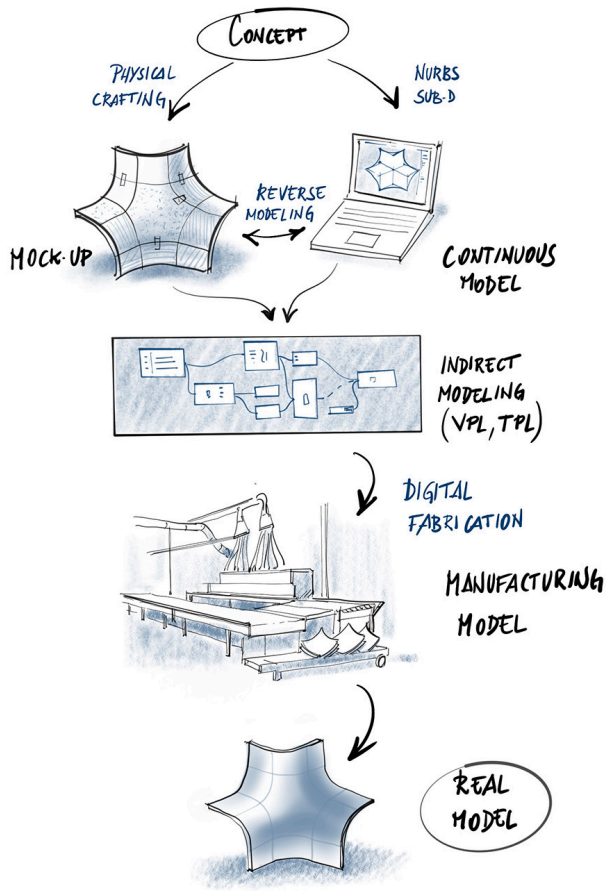


Fig. 1. Diagram of the modeling and form-construction process, from concept to realization (elaboration by the authors).

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.

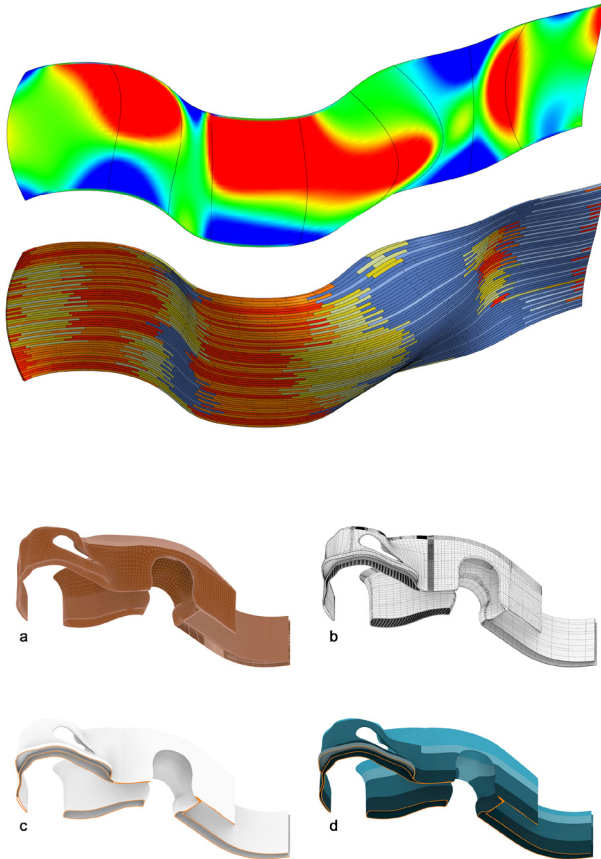


Fig. 4. Tessellation of the complex form in relation to the curvature parameter: greater curvature corresponds to shorter tiles; lower curvature to longer ones [Calvano, Mancini 2020, p. 112].

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 'simplicity', 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).

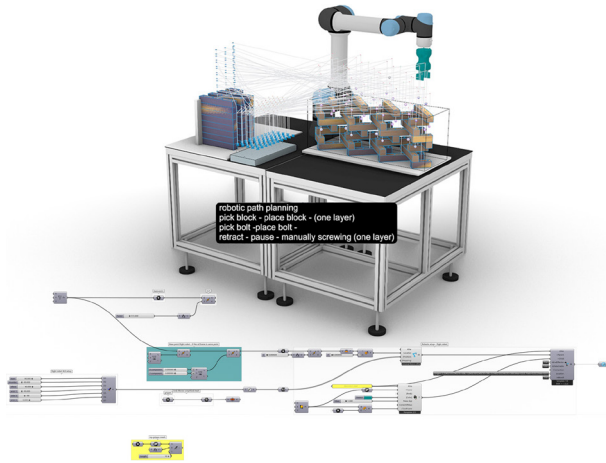


Fig. 7. Simulation of the robot-assisted construction process. Assembly parameters controlled through the use of VPL [Cognoli 2024, p. 284].

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.

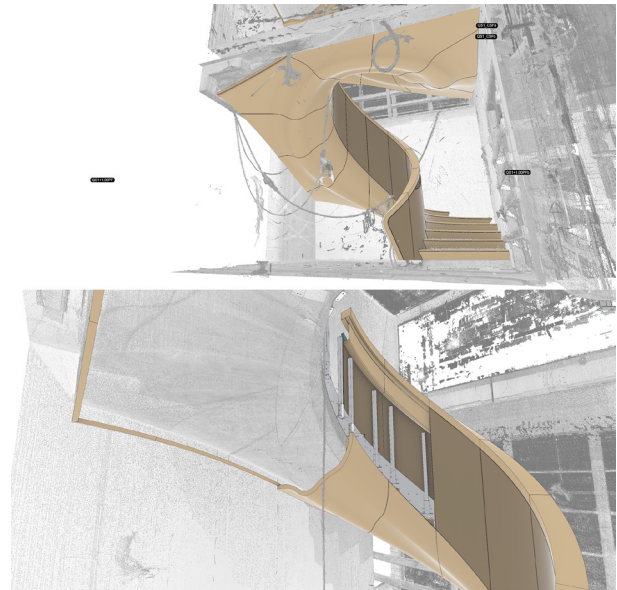


Fig. 8. Construction phases of the free form staircase. On-site installation and assembly of prefabricated modules manufactured in the workshop (photos: Devoto Design).

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:

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 atten-

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

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.

tion 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.

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/>> (accessed 18 June 2025).

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