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Digital Stereotomy as Paradigm Shift: Revisiting Theory, Geometry and Construction

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Abstract
Stereotomy theory has undergone a significant transformation, evolving from its classical paradigm as an art du trait toward its "revival" in the twenty-first century as digital stereotomy. This paper aims to critically analyze this transition through a literature review that highlights how different authors have approached stereotomy theory in relation to their respective historical contexts. It argues that digital stereotomy does not merely represent the application of technological tools to classical theory, but rather constitutes a fundamental paradigm shift that reintegrates geometry, mechanics, and construction into a single, digitally controlled process. The adopted methodology combines an epistemologically oriented literature review with the analysis of two case studies, enabling a critical comparison between digital and classical approaches to stereotomy. The results demonstrate that, although digital stereotomy reunifies the phases of stereotomic design within a single digital workflow, it has theoretically diverged from the classical definition of stereotomy as the art of stone cutting for the construction of load-bearing structures such as vaults and arches.
This study is intended to assist architects in distinguishing between practices that merely appear as stereotomy and those that engage with the architectural meaning of the stereotomic concept, as opposed to highly evolved and diversified digital techniques.

Keywords: *Art du trait, Epistemology, Material Intelligence, Robotic fabrication, Descriptive Geometry*

Introduction

When being formally defined, stereotomy is often described as both an art and a science, while in the etymology of the word we come across it as undeniably a technique of cutting. The word itself can assume many meanings and be very conceptually fluid, spanning from a rigorous technical methodology to a comprehensive and more abstract spatial approach. In our contemporary framework, stereotomy is evidenced by digital workflows which claim a radical act of modernizing the century-old practice known as art-du-trait. Besides practically, this act underlines theoretically a total transformation of the classic paradigm of the 16th-17th century and resurging in the 21st century as "Digital Stereotomy". This is made possible by the advancement of parametric and robotic fabrication technologies which enable stereotomic forms (which before demanded extraordinary manual craftsmanship) to be engineered through the computational analysis and workflow.

Consequently, the question arises as to whether digital stereotomy constitutes an evolution of the paradigm or a more fundamental transformation of it which diverges from the core principles that maintain it as a concept.

The objective of this research is to bring forward these principles and examine them when compared to the subsequent products of the digital methodology. The adopted methodology consists in a comprehensive literature review which highlights such differences and furthermore, two case studies are analysed to provide a critical comparison between the classical and digital paradigms of stereotomy.

Literature review

Taken from the point of view of "the art of stone-cutting and masonry construction", stereotomy has long functioned as a mode of architectural thought intrinsically linked to geometry and especially structural integrity (Aita, 2003). According to Jose Calvo-Lopez (2020) however, the discipline should be viewed as a framework for conceptualizing space and form through mathematical logic, rather than merely a construction technique. He posits that architects such as Philibert de l'Orme and Gaspard Monge elevated stereotomy into a design methodology where form itself was generated through rigorous geometric logic. These approaches were firstly informed by the treatises of De l'Orme where we first see stone cutting treated as an exercise in geometric projection (De l'Orme, 1567). De l'Orme developed a more exact method applicable to any type of trompe, contending that the stereotomy of his era lacked a unified system, which hindered its transmission as codified knowledge (Sanabria, 1989). It can be noted that he eschewed the mathematical formulas heavily prevalent in the Gothic architecture which he found insufficient for the new architectural demands of the French Renaissance, as they were more-so a product of trial and error as opposed to a transparent unified system. Apart from consequently "democratising" the craft, his main objective was to synthesize aesthetic requirements with the inherent constraints of the material (Sanabria, 1989, pp. 274-276).

However a more academic orientation is adopted by Alonso de Vandelvira, who parallel to De l'Orme addressed similar complexities in his own treatise, albeit in a more analogous geometric manner with tangible solutions. He used his complex drawings and templates as a method to develop the precise interlocking of the joints by solving the geometry of each individual stone component (Sanabria, 1989, p.298).

We can see stereotomy being reconceptualized from a pragmatic craft into a sophisticated apparatus from Guarino Guarini's engagement with the extensive work of Philibert de l'Orme which mars a very critical juncture in the history of architectural theory. Werner Muller (1968) suggests that Guarini did not merely adopt the methods of De L'Orme but the used them as a springboard to analyze the tensions and contradictions between applied geometry and theoretical abtraction. This transition is very evident is the distance that Guarini takes from the traditional stonecutting and later delving more into highly complex geometric configurations such as the intersections of paraboloids and conic sections.

It is through these complex forms that the role of the architect fundamentally changed. Since a level of mathematical rigor was required, the byproduct of the artisanal experience also shifted into a manifestation of deliberate theoretical vision. This tacit knowledge which derived from workshops and the operating traditions of the masonry guils (Montemurro, 2003) was further distilled into a codified set of rules by Guarini. The result of this can be viewed as as bridging the gap between the masonry yarn and the academy (Muller, 1968, p.204).

In this light, stereotomy emerges in Guarini's work as the intersection of mathematics and aesthetics, an elevation of the tectonic reality of construction to the status of an autonomous intellectual discipline that would define the trajectory of Baroque architecture and its subsequent development across the Mediterranean (Galletti, 2017).

To fully understand the rupture identified by Evans, it is critical to trace the trajectory of stereotomy through the Enlightenment and the Industrial Revolution, a period that fundamentally altered the discipline's epistemological status. Guarini elevated stereotomy to theoretical abstraction but it was the mathematician Gaspard Monge in the late 18th century who decisively codified it into the formalized science of descriptive geometry. Monge's curriculum at the École Polytechnique stripped the trait of its localized, artisanal mystery, translating it into a universal mathematical language intended for military engineering and industrial application (Calvo-López, 2020). This democratization of geometric knowledge, however, initiated the very detachment that Evans later laments. By separating the rigorous drafting of stereotomy from the masonry yard and institutionalizing it within the academy, the physical resistance of stone was gradually replaced by the frictionless logic of the drafting board. Consequently, the 19th-century reliance on iron and steel construction further marginalized stereotomy, reducing it from a generative structural logic to a mere historicized aesthetic. This historical digression shows how the digital paradigm's reliance on abstract computation is the culmination of a centuries-long trajectory that began with Monge's mathematical systematization,

a process that progressively alienated the architect from the tactile realities of the construction site.

This shift toward abstraction, while intellectually sophisticated, eventually prompted a critical counter-narrative in contemporary scholarship. Robin Evans (2000) offers a seminal critique of the architectural transition from a geometry rooted in materiality to one defined by visual abstraction. He traces the shift toward a detached, analytical framework, moving away from a "tectonic" geometry that emerged from the physical constraints of stone cutting (pp. 3–17). This evolution represents a fundamental rupture in the history of design, as modern architecture became increasingly reliant on projective and Cartesian geometries, effectively discarding the spatial richness inherent in traditional stereotomy.

For Evans, this abandonment signifies a profound "loss of complexity" and a diminishing of the intellectual engagement between the architect and the material (pp. 55–72). In the stereotomic tradition, form emerged as an organic byproduct of the dialogue between geometry, gravity, and the lithic medium. To substantiate this claim, Evans revisits the innovations of Philibert de l'Orme and the 17th-century French masters (pp. 97–103). He identifies their work as a peak of "operative geometry," where the drawing functioned as a precise set of instructions for physical production, transcending simple representation. These early practitioners utilized geometry as a primary method for producing space through a continuous synthesis of thought and matter (pp. 108–120). Ultimately, the work of both Calvo-López and Evans highlights a historical weakening of the bond between drawing and construction which is a connection that once defined the essence of stereotomic mastery.

While Evans identified bond, the contemporary digital turn offers a potential closing of the epistemological gap that exists between geometric abstraction and material reality. The resurgence of the digital suggests a path which reconciles the "operative geometry" Evans admired with the modern computational approach.

Such digital technologies and the advancement of computational design have produced a renewed fascination with the stereotomic principles (Fallacara, 2006) which facilitate the emergence of "Digital Stereotomy" (Fallacara, 2005). This concept itself is a critical re-evaluation of the classical methodologies but does this through the lens of a contemporary logic and practically through robotic fabrication. This technology allows for precise machining of lithic components and re-introduces the logic of construction into the generative design process.

Their integration modernizes the craft and also offers a direct response to the historical fragmentation identified by Evans by reuniting design intent with material performance. This computational reconciliation finds its most potent expression in the contemporary focus on material sustainability and the advent of high-fidelity three-dimensional modeling (Fernando et al., 2009).

These catalysts have necessitated the definition of a new paradigm, which Giuseppe Fallacara terms "Stereotomy 2.0" (Fallacara & Barberio, 2018a). This framework facilitates a transition from two-dimensional representation toward three-dimensional realization, integrating computational design with concurrent structural analysis. In this model, static performance actively dictates the resulting architectural form, ensuring that the final output is a direct reflection of its internal forces.

Central to this modern approach is the "Stereotomy Paradox," a principle that has underpinned the discipline from the 16th century to the present. Traditionally exemplified by masters such as Philibert de l'Orme, this paradox involves leveraging heavy materials (specifically stone) to create structures that appear to defy gravity by utilizing the physical force of compression. Stereotomy 2.0 adopts this logic, demonstrating that material weight and compression/tension performance can be harnessed to produce structures characterized by an aesthetic "lightness" while maintaining rigorous static stability (Fallacara & Barberio, 2018b).

Complementing this structural philosophy is a design methodology inspired by Michelangelo's poetics of "building through excavation." This concept frames the design process as an act of elimination, revealing the final form within the material rather than imposing an external shape upon it, akin to a sculptor discovering the figure hidden within a block of stone. Within the digital paradigm, this subtractive approach incorporates a "geometrical-ethical" dimension, prioritizing the minimization of waste and the responsible stewardship of non-renewable raw materials (Fallacara & Barberio, 2018).

Stereotomy 2.0 claims the optimization of material cuts through algorithmic design, ensuring minimal resource loss during production. While some degree of residual waste is inherent to the process, contemporary fabrication technologies allow for its strategic reintegration into the workflow. This hybrid methodology effectively bridges the gap between traditional subtractive techniques and modern assembly methods. Furthermore, Stereotomy 2.0 extends the material palette beyond traditional stone to include artificial and composite materials, defining the discipline through the application of volumetric components rather than specific material properties.

In this context, the definition of stereotomy expands toward a "science of cutting solids," introducing a new "Geometric Ethos" focused on near-zero waste through CNC and robotic fabrication (Fallacara & Barberio, 2018). This digital workflow repositions the practitioner as the Novus Architetto Adaucto, a figure who regains comprehensive control over the entire architectural process, from initial conception to final physical production (Fallacara & Barberio, 2018).

Although the Novus Architetto Adaucto regains systemic control, this engagement is fundamentally shifted from the physical resistance of the lithic medium to the manipulation of algorithmic parameters. Consequently, the discourse prioritizes geometric efficiency and resource stewardship, yet largely leaves unexamined whether the digital workflow truly recovers the "operative" dialogue Evans admired or if it simply replaces the historical detachment of the drawing with a new, data-driven distance from the material's tactile reality.

Methodology

To illustrate this gap between the critical theory and the evolution of the steretomic paradigm, this research is based on a comparative methodology which confronts two qualitative case-studies. The epistemological transition is evidenced through an analysis of the two key moments in the development of the discipline: The Chateau d'Anet is chosen as the exemplary of the classical paradigm and the Hypar Vault as a prime example of the contemporary digital paradigm.

The criterion of these choices is based on the fact that they both represent the pinnacle of innovation in their respective eras. The Chateau d'Anet was projected by Philibert de l'Orme himself (around 1547-1552) and marks the apex of the application of Descriptive Geometry for the solution of complex problems related to the stone-cutting, all of this before the birth of modern engineering. On the other hand, the Hypar Vault is considered by Fallacara and Barberio (2018) as a crucial experimental laboratory for that they call "Stereotomy 2.0".

The analytical framework of this comparison is built upon the deconstruction of four core principles: structural integrity and the joint typology, material authenticity, modularity of the elements and the volumetric logic. These principles primarily derived from the work of Philiber de l'Orme are critically reviewed to extrapolate the claims of the digital revival as opposed to the loss of the connection between drawing and materiality as stated by Evans (2000).

Results and discussions

The detailed comparison of the Chateau d'Anet with the Hypar Vault unveils a series of technic and conceptual dissonances which challenge the claim that "Stereotomy 2.0" is a pure continuation of the classical tradition. The results show that the comparison of the digital paradigm to the classical one showcases a very crucial divergence of the former from the core principles of l'art du trait. This technique has its optimal case depicted in the Chateau d'Anet which is a masterpiece of the French Renascence. It marks the pinnacle of the application of descriptive geometry for the resolution of much more complex problems related to the stone-cutting technique before the birth of modern engineering and digital calculation. As a technique, its essence lies in the ability to define with accuracy the three-dimensional morphology of each individual stone achieved through two-dimensional projections. These accurate projections make possible the perfect fit of the blocks which form a self-sustaining vault. As a result the whole structure is defined as an autonomous system.

This is properly illustrated through its architectural elements. The dome (fig. 1) is composed of stone blocks cut with extreme precision and interlocked according to a well-established rhythm. It functions as a monolithic shell which allows it to be self-supporting which demonstrates the capacity of stereotomy to achieve wide spans through geometry.

Similarly, the Trompe d'Anet (fig.2), a conial corner vault is esteemed for its bold use of construction technique where the internal compressive forces of stone are leveraged to create the idea of a structure which defies gravity. It is almost a structural paradox where geometry "traps" it and engineers the possibility of that shape. The resistance of the stone is a variable in the equation which dictates the drawing.

This same approach is claimed for the design process of the Hypar Vault (fig. 3), one of the most important representative cases of the digital renascence of classical Stereotomy. Fallacara and Barberio consider it as an experimental laboratory where geometry, material and structural forces are tested to be integrated through technology into one cohesive design process (Fallacara, 2018). In the classical tradition of the "art du trait" the architect defined form through the means of geometric rules and two-dimensional drawings. However, in the Hypar Vault form is defined by the form of the pre-fabricated modules. There are two types of modules and they are the mirror image of each-other. Their designs are based on the hyperbolic paraboloid which is one of the only surfaces with two directions in geometry. In this project it is chosen as a shape that synthesizes the logic of tension and structural compression. These blocks have axial perforations where steel cables pass through. We can see that contrary to the traditional stereotomy such as that of Anet, the joints are not self-sustaining but require the assistance of cables. It can be argued that this introduction of axial perforations is a departure from the structural integrity of the classical vault which was a direct consequence of geometrical interlocking of individual voussoirs. By passing steel cables through the stone Digital Stereotomy transforms it into a composite material which goes against the principle of Material Honesty (Frampton, 1995) found in De l'Orme's work. In the Hypar Vault the geometry is therefore a product of form-finding optimization rather than the operative origin that dictates the structural possibility. In the classical paradigm a vault became stable in the moment the keystone was dropped into place and the internal forces were resolved. This is something which is mechanically missing in the digitally produced one, the latter not being self-supporting in the traditional sense.

A further philosophical dissonance arises when evaluating the epistemic transparency of the structural stability in both paradigms. In classical stereotomy, the geometry itself served as the irrefutable proof of stability; the master mason possessed absolute epistemic clarity because the physical structure was an unmediated, 1:1 reflection of the trait. The form stood precisely because the cut was correct. In contrast, the Hypar Vault and the broader Stereotomy 2.0 framework introduce a highly mediated layer of computational simulation, specifically Finite Element Analysis (FEA), to guarantee structural viability. While this allows for the generation of unprecedented, highly optimized forms, it simultaneously constructs an intellectual "black box" between the designer and the physical outcome. The architect does not intuitively "know" the structure will stand through geometric logic alone; rather, they rely on the output of algorithmic stress-tests. This shifts the validation of architecture from the tectonic intuition of the maker to the predictive probability of the software, thereby cementing the exact loss of operative intelligence that Evans critiqued in modern practice.

One of the most radical departures of Stereotomy 2.0 from the



Figure 1. The dome of Chateau d'Anet

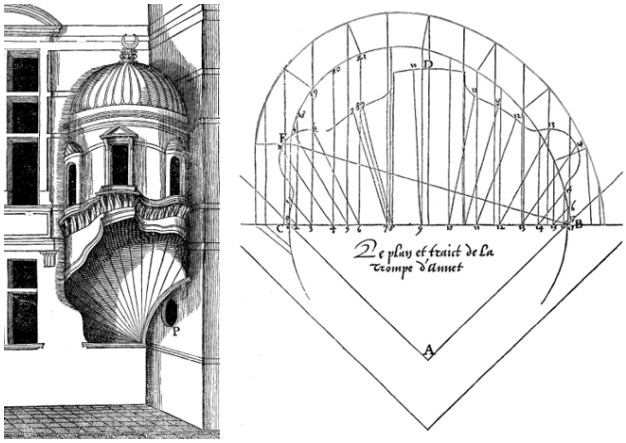


Figure 2. Trompe D'Anet and its geometric projection

classical craft is the use of recomposed stone. Much of Fallacara and Barberio's research focus on utilizing stone dust and cement to create molded or 3D-printed "stone" blocks. This treatment is a very big leap away from the lithic identity and cutting act of the trait that defined it as a discipline.

Furthermore, the ecological justification for Stereotomy 2.0 as seen on the ArchDaily (2018) title "This Stone Vault Prototype Creates Almost No Material Waste", warrants a critical deconstruction regarding its impact on material authenticity. The employment of recomposed stone is championed as a sustainable solution to quarry waste. This practice undeniably achieves efficiency in both an economic and environmental point of view but it does so at the cost of fundamentally rewriting the ontological definition of mansory because it liquefies and moulds the material or it extrudes through 3D-printing nozzles which inevitably treats the stone as an isotropic and plastic medium, quite contrary to its fundamental nature. This erases the inherent anisotropy of natural lithic formations, the grain, the bedding planes, and the natural flaws that historical masons had to respect and negotiate during the cutting process. Consequently, the "Geometric Ethos" of zero-waste inadvertently sacrifices the tectonic friction between human intent and natural constraint. The architecture is no longer born from the subtraction of solid mass, but from the additive logic of industrial manufacturing, stretching the definition of stereotomy to a point where it merely mimics the visual aesthetic of stone construction without retaining its heavy, material reality.

Another technical and philosophical "violation" that would be against the classical paradigm of Philibert de l'Orme has to do with the modularity of the parts. In the classical one each voussoir is typically a singular unit because vaults were often asymmetrical and adapted to a specific regular site. This meant that the master mason had to project unique geometry for each stone and this "rule" produced a very organic whole of distinct



Figure 3. Hypar Vault

parts. However, when analysing the Hypar Vault we can notice that the use of only two distinct units (fig. 4), each being the mirror image of the other and rhythmically repeated. This introduces an industrial and serial logic to stereotomy, a kind of "ready-to-wear" system as opposed to the more "tailored" one of the classical system. Arguably it achieves economic efficiency but it sacrifices the specific local adaption of the trait.

In the logic of "violations" the broadest one is noticed in the overall shape of the structure itself. The vault is named after the Hyperbolic Paraboloid, a mathematical surface, a product of modern calculus and optimised for membrane behaviour. However, Stereotomy is conceptually founded on the idea of hollowing mass and as such, it is intrinsically volumetric. Digital Stereotomy, treating stone as a thin membrane, bypasses the core principle of a vault's strength.

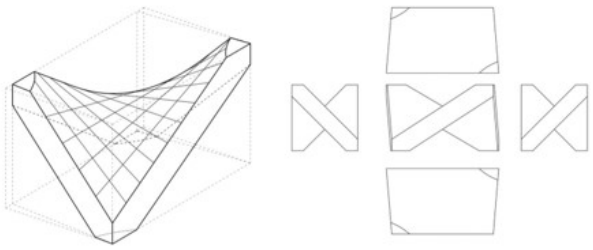


Figure 4. The Hyperbolic Paraboliod modules

Conclusions and recommendations

In the final analysis, this research drops the illusion of an uninterrupted continuation between the classical mastery of stone cutting and the contemporary fabrication, positing the claim that "Stereotomy 2.0" does not establish a purely nostalgic return to the art du trait, but it is necessary to observe it as a deep ontological mutation of the discipline itself. Even though the digital technology and robotic fabrication offer to the architect absolute control over the geometric complexity, it achieves this "revival" by sacrificing the autonomy of the material itself. Placed against the classical principles, it is evident that the stone stops being a primary agent which dictates the genesis of the form and this is due to factors such as the reduction of mass, introduction of hybrid binders and recomposed materials.

However, this observation does not assume the de-evaluation of this digital transition. It's innovation and even ecological ethos are technically independent while a further interrogation is crucial to the area left undisputed. While the classic stereotomy is an act of straightforward translation from mind to matter, the software of the parametric design is claiming an epistemological gap where drawing and geometry lose their status of tactile dialogue with gravity in exchange for an abstract negotiation with parametric code.

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