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Contemporary Stereotomic Trait, an Opportunity for the Development of the Volumetric Digital Architecture

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Stereotomy is generally known in architecture as a stone carving technique for the purpose of constructing masonry assemblies. A deeper analysis reveals stereotomic design processes' ability to resolve multiple structure and construction constrains, derived as underlying geometries and their relationships, into architectural volumetric complexities. The paper argues that the trait, stereotomic geometric negotiations platform, re-examined in a contemporary context, lends itself as a theoretical model for the current digital architecture's pursuits of multiple constraints assimilations within design processes and their physical reflection in formal complexities.

Keywords: stereotomy, trait, digital architecture, digital design

INTRODUCTION
The contemporary notion of stereotomy in architecture is restricted to designate the stone carving technique for the purpose of constructing masonry assemblies.

The word’s etymology defines a broader meaning of three-dimensional solid cutting into shapes to be assembled. Historic studies that encompass form taxonomies, their practical and theoretical evolutions, and cultural assimilations illustrate a wider polymorphic diversity (Sakarovitch, 2003).

Stereotomy, re-examined in a contemporary context due to its intrinsic qualities offers an opportunity to respond a volumetric lacuna within digital architecture.

More specifically, as this paper argues, the stereotomic trait understood as the Deleuzeian objectile lands itself as the crux for resolving multiple structure and construction constraints into volumetric complexities.

VOLUMETRIC LACUNA IN DIGITAL ARCHITECTURE
Stereotomy originated at the overlap of several disciplines: architecture, mathematical geometry, technical drawing, structural theory, practical masonry, and military engineering. Shared by all, it flourished where definitions blurred, where one thing began to glide off into others, as an unrecognized border joining many diverse regions (Evans, 2000). A mutual knowledge exchange was generated between all disciplines involved due to the common reliance on geometry. As stereotomy was increasingly approached as correct understanding of geometry (Heyman, 1995) the knowledge exchange became more fluent. By the end of the nineteenth century this generated progress in all the disciplines in the areas of design, representation and fabrication of complex geometries, “freed from Euclidian metric” (Sakarovitch, 2003).
Complex stereotomic geometries developed due to the design attitudes that regarded 'difficult' as a superlative. Difficulties were as much sought after as found (Evans, 2000): ever greater formal complexity, elaborate ornamentation, and daring statics that appeared as effortless as their visual comprehension (Figure 1). Their design processes necessitated concurrent handling of multiple structure and construction constraints and their interdependences. Structure, an abstract concept, was geometry-based statistics (Sakarovitch, 2003) principle destined to cope with the contextual force flow. Construction, its concrete realization, was carried out in a number of materials (Sekler, 2009), tools, technologies and procedures, fabrication constraints, and design, geometric, and instrumental knowledge (Witt, 2010). Design processes derived structure and construction constraints as geometric constraints and formulated form as their continuous negotiations. Design knowledge on multiple constraints handling was deduced, embedded, and instrumentalized in geometrical tools and procedures (Witt, 2010) that enabled volumetric complexities, topological transformations, variations, and differentiations. In short, stereotomy became the epitome of architectural complexity by acknowledging the centrality of geometry, tools, and procedures in the design process.

In the twentieth century, there was a paradigm shift in architecture that prioritized economy of design, fabrication and construction. Efficacy-driven design processes abstracted machine constraints to achieve repeatability, speed, and mass production (Witt, 2010) towards structure and construction rationalization. As a result, design processes favoured steel and concrete as materials, standardization as modus operandi, and scarce geometries as aesthetic expression (forms that were assumed too complex to be machine produced were marginalized (Witt, 2010)). Stereotomy could not compete in this milieu. It required extensive geometric and tacit knowledge, intensive fabrication due to varied ashlar configurations, and lengthy, costly construction processes due to elaborate falsework. Stereotomy was shunned and abandoned into the realm of "forgotten geometries lost to us [architects] because of the difficulties of their representation" (Moneo 2001, cited Kolarveic 2004).

The advancements in resolving multiple design constrains as geometric complexities continued through the knowledge exchange between sciences and other industries. Since a great number of the industries (aviation, automobile, and shipbuilding) were based on sheet materials, the geometric research focused primarily on surfaces. The geometric research into volumetric complexities dealt with either the small scale (product design), or was not concerned with material resolutions (digital modeling and animation).

By the end of the century, the accumulated geometric knowledge was embedded in different CAD and CAM digital tools making it easily employable. Appropriated by architects, digital tools expanded the architectural formal repertoire by enabling the complexity of conceived forms and their transfor-
They provided physical resolves for the theory driven by the Deleuzeian Fold and the form defined by the rules of its variations (and variations of variations), an objectile (Carpo, 2011). Digital tools did not require users’ understanding of the embedded complexities to handle their design, representation, fabrication, and construction. They were attained through instrumental knowledge that directly enabled or disabled the act of design (Witt, 2010). In this way, knowledge on resolving multiple constraints, directly borrowed from the other industries, was only partially assimilated into architectural design knowledge. Digital architecture did not establish large scale volumetric form actualization processes based on intrinsic, multiple constrains and remixed surface-based. “Paradoxically, quest for depth led to an infatuation with the façade or skin, in other words with superficial, the two-dimensional” (Picon, 2010).

STEREOTOMY, COMPLEX VOLUMETRIC ARCHITECTURE

Stereotomic design processes, as comprehensive resolutions of multiple structure and construction constrains, offer a valid framework for establishing digital architectural form formation processes. The central aspect of stereotomic design processes was deriving structure and construction constrains as geometric constraints and their relationships. Stereotomic form emerged from multiple, neither hierarchical nor discrete, underlying geometries: assembly geometry, ashlar geometry, structure geometry, falsework geometry, and geometry defined by tools and procedures. Their sub-stereotomic interdependencies were almost non-exhaustive.

The structure geometry formulated structure and assessed its appropriateness and efficacy (Sekler, 2009). Jointly, the assembly and ashlar geometries were in a formative interdependency with the structure geometry: any assembly and its ashlars were subservient to structure, and concurrently, through their shape
and proportions, ensured stability (Heyman, 1995), the validity of the structure geometry (Figure 3).

Further, structure geometry responded to the varied force flow at each construction process stage. Together with the assembly geometry and construction assembly constraints, it determined the falsework geometry. At the same time, due to its necessary optimizations (towards fast, simple mounting and dismantling, the ease of use and reuse, etc. (Figure 4)), the falsework geometry influenced the assembly and structure geometries formulations, and determined construction assembly sequencing.

Similarly, a continuous coevolution developed between tools and procedures, and their embedded knowledge. As a result, the geometric rigor, precision, and control improved and, in turn, improved the design of the drafting, fabrication, and construction tools and procedures (Figure 5).

Despite the immanent geometric presence throughout, stereotomy showed less obvious trace of geometric regulation: by using more geometry, it appeared to be used less (Evans, 2000). As the negotiations proficiency within the system of sub-stereotomic geometries increased, so did the pursued stereotomic complexities, and stereotomy became more stereotomic.

**STEREOTOMIC TRAIT**

The platform for sub-stereotomic geometric negotiations was the trait. Traits were preliminary drawings that allowed design and definition of assembly and ashlar geometries, and regulated their configurations to ensure buildability. Simultaneously, they were layout drawings that enabled precise ashlar fabrication, falsework design, and construction sequencing (Figure 6). Traits enabled geometric generative rules formulations, form variations computations, and their executions.

The initial motivation for the trait establishment was to record and dissipate the oral secrets of the masons’ lodges in a drawing format. Throughout history, their representational role transformed to a didactic one. The focus shifted from cataloguing the existing assemblies towards communicating the underlying ge-
ometric processes to facilitate original designs and wider theoretical and practical explorations of two-dimensional into three-dimensional transformations (Sakarovitch, 1998).

Progressively, traits theorized and generalized stonecutting problems, abstracting them into spatial studies. Further, traits instrumentalized stereotomic design knowledge, derived from merging practical, traditional, local knowledge with universal, scientific knowledge, into geometric procedures. Traits embedded master masons’ applied and mathematicians’ erudite geometric knowledge (Sakarovitch, 2003) to become drawing ‘machines’ (Witt, 2010).

During the traits’ evolution, graphical techniques based on geometric representation were initiated (Sakarovitch, 1998). Later a geometric language was established that enabled mutual interconnections, multiple interpretations and open-ended relationships. It made the embedded knowledge accessible and susceptible to development and assimilations. By the nineteenth century, traits facilitated knowledge exchange between stereotomic design, scientific geometry, conceptual geometric procedures, irregular stonecutting procedures, and drafting instrument developments.

The positive feedback loop outcomes were, among others, the Descriptive Geometry formulation, geometry of curves and curved surfaces advancements, drafting instruments with embedded complex geometric knowledge, and the stereotomic architectural peak (Witt, 2010) (Figure 7).
In the contemporary architectural theory realm, traits could be understood as objectiles. An objectile, an open-ended algorithm based on a parametrical function, determined infinite object variations, all different (from one parameter set) yet all similar (from the same underlying function) (Carpo, 2011). Similarly, specific stereotomic elements belonged to a general category and were differentiated by the trait. For example, the arch trait, a geometric procedure, differentiated a specific arch for the specific context from an infinite number of arches. The arch trait was the structure and construction negotiation expressed through underlying geometric interdependencies. As a fixed normative genus, the trait was exactly transmissible but nonvisual notation that embodied infinite variations, clearly different yet similar forms (Carpo, 2011).

Trait, like objectile, had two types of authors: the author that designed the (or a series of) generative notation(s) that are general, genetic, and parametric, and the author that specified the notion(s) in order to design individual forms (Carpo, 2011). Throughout history traits’ author pairs changed and multiplied: master mason and stone carver, architect and master mason, scholars and geometers, etc.

The multiple authorships and geometric negotiations defined traits’ multifaceted nature and varied legitimacy from practical validations through execution to theoretical rationale affirmations. Their role, in Deleuzeian terms, remained singular and clear: to differentiate multiple sensible forms from virtual, abstract ideas (Moussavi, 2009).

DIGITAL ARCHITECTURE TODAY

The dominant design attitudes (New Structuralism (Oxman, et al. 2010), Material Computation (Menges, 2012; Menges, 2015), FABRICATE conferences (Sheil, et al. 2017), etc.) in the current digital architecture argue for necessary multiple design constraints (structure, climate, material, fabrication, etc.) assimilation within design processes and their physical reflection in formal complexities. Akin to stereotomic, digital design processes are driven by intrinsic structure and construction constraints and strive to formulate genuinely architectural form formulation processes. The technology context, instigated by diversity of contemporary digital tools, provides architecture with vast opportunities that, when translated into multitude of constraints, can concurrently hinder them. This is reflected in the challenge to resolve multiple constraints as large scale, volumetric complexities.

The renewed interests in stereotomy, facilitated by the digital tools availability, initially focused on previously difficult to achieve formal complexities designs and explorations, topological transformations, precise varied irregular ashlar configurations fabrications, and complex structural resolves. In the recent years, stereotomic rule-based design processes, parametrized into digital associative geometry models, enable a number of assimilations to directly informe form formations: contemporary geometric knowledge, material limitations, structural optimizations, CNC/robotic fabrication requirements, etc. (Fallacara, 2012; Fallacara, et al. 2015; Fallacara, 2016; Rippmann, et al. 2011; Rippmann, et al. 2017; Burry, 2016; Varela, et al. 2016; Fernando, et al. 2015; Weir, et al. 2016; Clifford, et al. 2015). The resulting forms illustrate the digital tools and procedures ability to proficiently control and handle underlying geometric negotiations, as an overlap of assimilated constraints (Figure 8) into volumetric complexities. Unfortunately, they preserve stereotomy’s stumbling block that originally denied it viability: the costly, elaborate falsework (Figure 9).
CONTEMPORARY DIGITAL TRAIT
The aim of this paper is to understand trait’s historic nature and theorize its contemporary relevance and drawbacks towards its adaption to the digital realm. Contemporary digital trait, developed as geometry-driven objectile, offers “open-endedness, variability, interactivity, and participation [that] are the technological quintessence of the digital age” (Carpo, 2011). More specifically, it offers the possibility of becoming the crux of resolving multiple architectural constraints as volumetric complexities.

The contemporary trait necessitates reinstating of its intrinsic nature and certain adjustments. The primary role remains: computation-based platform for multiple structure and construction negotiations abstracted as geometric constraints and their interdependencies. The knowledge embedded in a trait remains open source: easily accessible, communicable, repeatable, hackable, and transformable (Witt, 2010). On the other hand, the trait’s authorship requires redefinition from the demarcation and polarization of the historic types, into a gradient that spans the two. The fluid authorship enables multiple trait authors and concurrent knowledge embedding and activating to instigate collaborations and innovations at multiple levels. In this way, the contemporary trait can narrow, if not fully challenge, the Albertian splits as “the synthesis of architect, engineer and fabricator again controls the historical responsibility for the processes of design, making and building” (Oxman, et al. 2010). Further, the authorship fluidity through participation and novel connections sustains knowledge exchange, development and assimilation between theory and practice, industry and academia, traditional and contemporary, and local and global.

Conclusion
Volumetric complexity is primarily the domain of architecture and its viable resolve is possible only through architectural design knowledge and innovations. Through comprehensive multiple structure and construction constraints negations, complex volumetric forms, differentiated through digital traits, articulate meaningful tectonics as a particular empathy manifestation in the field of architecture (Sekler, 2009). In a wider contemporary digital theory realm, the trait enables architectural tectonics that addresses a number of its pursuits: Moussavi’s affects (Moussavi, 2009), Spuybroek’s sympathy (Spuybroek, 2011), Picon’s narrative and nostalgia (Fabricate 2017 conference lecture), etc.

The first step, though, remains to overcome the historic stumbling block: the assembly construction as feasible and timely process through all relevant constraints computation.

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