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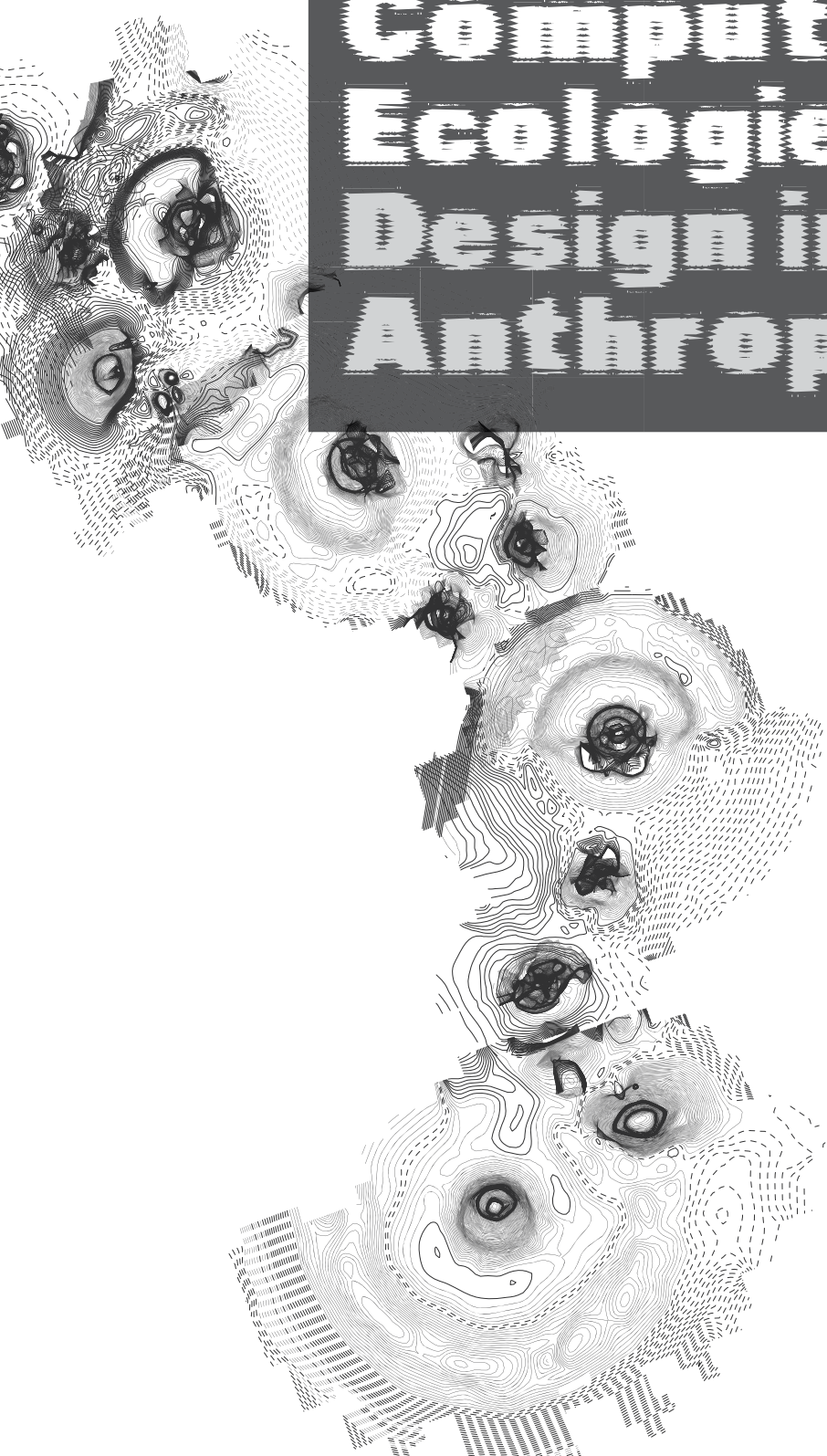
Computational Ecologies: Design in the Anthropocene

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DATA MAPPING AND ORNAMENT IN DIGITAL CRAFT

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ABSTRACT

With an ever-increasing index of digital artifacts, we have begun to exhaust variation as an adaptive technique. The problem with incremental modulation (here understood as sequential and slowly progressing change of a set of parameters within a field condition) is that it leads to morphologically equivalent and repetitive patterns of habitation. While the role of variation proved necessary in pushing forward an essential body of research testing and optimizing principles of mass customization, its residual effects can become trivialized.

This paper presents an investigation of data mapping for the generation of form, seen through data analysis experiments and machining artifacts. Through several phases, we investigate the effects of ornament created as a result of the new relationship between generative modeling, analysis, and fabrication in the digital age. The ornament can be understood as a result of overlaid data, whether the data is performance related or not, in both massing and surface conditions. This new working methodology mitigates between the uncertainty regarding environmental, structural, functional requirements, and aesthetics. By reinventing their relationship, the method reassesses ornament's performance within the digital discourse.

Design methods are extended by exploring, collecting, analyzing, and representing data through various materialization processes. The ornament is reconsidered as being injected with the concepts of data driven design and dependent on the interplay between performance and aesthetics.

1 INTRODUCTION

With the emergence of digital technologies and parametric design, there has been a corresponding and growing interest in digital ornament and craft. Digital technology can be a vehicle to create astonishing ornamental complexities, as seen, for example, in the work by Michael Hansmeyer and Evan Douglass. Ornament, which has always been associated with materials and tools, was traditionally understood as the result of analog operations. Under the new data-driven design and fabrication processes, it becomes necessary to define and explore the nature of ornament as a function of both aesthetic and performance. Kyle Miller argued that "rather than being viewed as additive or an appliqué, ornament can now be understood as an integrated, performative, functional building component, one that bears technical responsibilities such as enclosure, aperture, daylight modulation, and temperature control, as well as the aesthetic and affective considerations that augment the visual potency and overall emotive qualities of a contemporary structure, and more specifically, a contemporary building facade" (Kyle 2011). The authors experiment on a series of case studies that investigate digital ornament at its tectonic level and fabrication processes. Several design and fabrication methods were examined while utilizing various techniques such as generative design and theories, performance analysis, data mapping, and CNC tool path customization. Precedent research on the history of ornament was conducted to compare and understand relations between digital technologies and analog methods and to gauge their historical impact. These findings demonstrate the convergence of hybrid methodologies influenced by the concept called "data as ornament."

2 METHODOLOGY

The use of craft can best be described by the terms *techné* and *fabricate*. Its origin suggests a deeply connected relationship to the process and the maker. With the emergence of digital technologies and new "workmanship" (Pye 1995), design now allows the use of computer to "automatically" drive forms and its ornament details. For instance, in Michael Hansmeyer's "Mesh to Ornament" project, the subdivision algorithms for the production of three-dimensional ornament exhibits an astounding degree of complexity. The external information such as generative rules, environmental, structural or social data can be used to generate complex ornamental effects. The ornament becomes the representation of data through a transparent and less subjective relationship. In the context of this research, new data driven processes have been developed into several different design strategies, which eventually are integrated with digital fabrication using computer controlled processes. This methodology is divided into three phases (Figure 1).

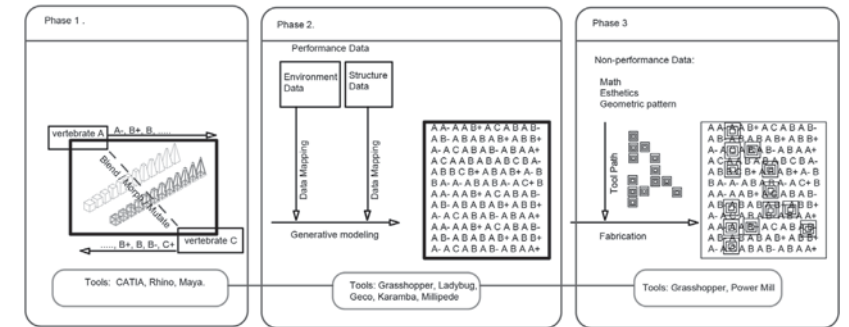


Figure 1
Three phase design-fabrication process.

3 PHASE 1. VERTEBRATE

The investigation builds on the historical significance and theoretical impact of John Frazer's *Evolutionary Architecture*, M.C. Escher's experiments in (de)generative morphing, and Manuel De Landa's "abstract vertebrate" and "material expressivity". Building on these ideas we explore computational possibilities driven by in-depth studies and analysis, decision-making, and design prototyping.

Comparatively speaking, evolution methods are successful in nature, but, prior to the computational era, a major constraint had limited the use of these processes in architecture. As described by Manuel De Landa, by producing "a kind of 'abstract vertebrate', "evolutionary" approaches can be used to optimize performance. The design process is no longer depending on architects' intuition and personal experience to make design decisions, but rather using data and relationships to define the design logic.

Juxtaposing strategies situated at the intersection of digital mass customization and digital fabrication techniques, we negotiate between the promise of control offered by the mathematical equation and the freedom from constraints inherent to any creative process. In this way, we offer as an alternative to the digital/analog dichotomy, a "vertebrate" model. The embedded variables of this initial model (A in Figure 1) allow it to transform into a different malleable model (C in Figure 1). A cluster of their transitional "offspring" (A-, B+, B...C+) can form complex systems with a variegated ordered inspired by the self-organizing processes of nature. As a simplified approximation of a natural system, a group of prototypes (A, B, C) is fully modeled to evaluate its performance. The virtual model allows designers to test and rework the prototype until it reaches the desired performance level. This process sometimes results in a physical prototype that allows the analysis of material properties and behaviors. With the goal to develop the complex relationships between forms, space, structure, materiality and the senses, this provisional method establishes a carefully documented proposition for future modes of inhabiting and constructing the built environment.

This initial step has a key role in establishing rules and later pseudo equations to determine assembling scenarios. Evolved from a singular vertebrate, the transforming models (A to C) are populated into a system for redistributing programmatic function in subsequent steps. The somewhat disjointed replication of spaces through the applied spatial grammar anticipates computational techniques that propose an evolution from the concept of vertebrate to data mapping.

4 PHASE 2. DATA MAPPING

Similarly to mapping a texture image across a 3D surface in a computer modeling software, abstract data can also be "mapped" to a form based on its geometric coordinates or various projection methods. Bump mapping and displacement mapping are two techniques widely used in the CG field. Advanced software such as ZBrush or Maya can generate 3D ornamental details on a geometry directly by mapping a bitmap or a procedural texture. John Elys has researched this mapping method in the architectural context. He stated that the mapping process that allows "the resolution of displacement is set to enter an unprecedented level of geometric detail" (Elys 2006). Inspired by Elys's research on creating ornament-based on mapping 2D maps, we explored how a set of data can be mapped and used to drive complex ornamental effects across a 3D form. The homogenous form is then translated into a representation object that can respond to different data values. Here, the hosting form is no longer responding to Cartesian coordination, rather to a multitude of relations of the projected data coordinated to the mapping strategy. Two experiments are discussed in detail.

4.1 Mapping Environmental Data

In this strategy, data mapping is used to register performance-related information and becomes a new design instrument for creating digital and physical representation through ornament. We explore how to anticipate the morphological change of architectural elements and embed the potential changing variables into a "vertebrate" component which responds to the performance data generated from solar, wind, and acoustic simulations. Environmental analysis tools such as Ladybug and Geco allows for form-finding and optimization techniques. These tools are applied to evaluate individual offspring (A, A-, ...C), as well as evaluate the entire hosting surface to generate an overall global map. In the experiment titled "Tidal Wall", the environmental data was used to describe the relationship between ornament and acoustic effects. All wall panels are individually optimized based on the acoustic performance data received from our simulation engines. The prototype was then fabricated using a combination of laser cutting and CNC milling techniques (Figure 2).

In this experiment, a procedure was developed to embed the acoustic data into a raster image. Each of the two hundred adaptive panels responds to the image input independently. We used the concept of texture mapping to develop a matrix of panels to form a wall system. The acoustic data represented by color values in a bitmap was inputted to

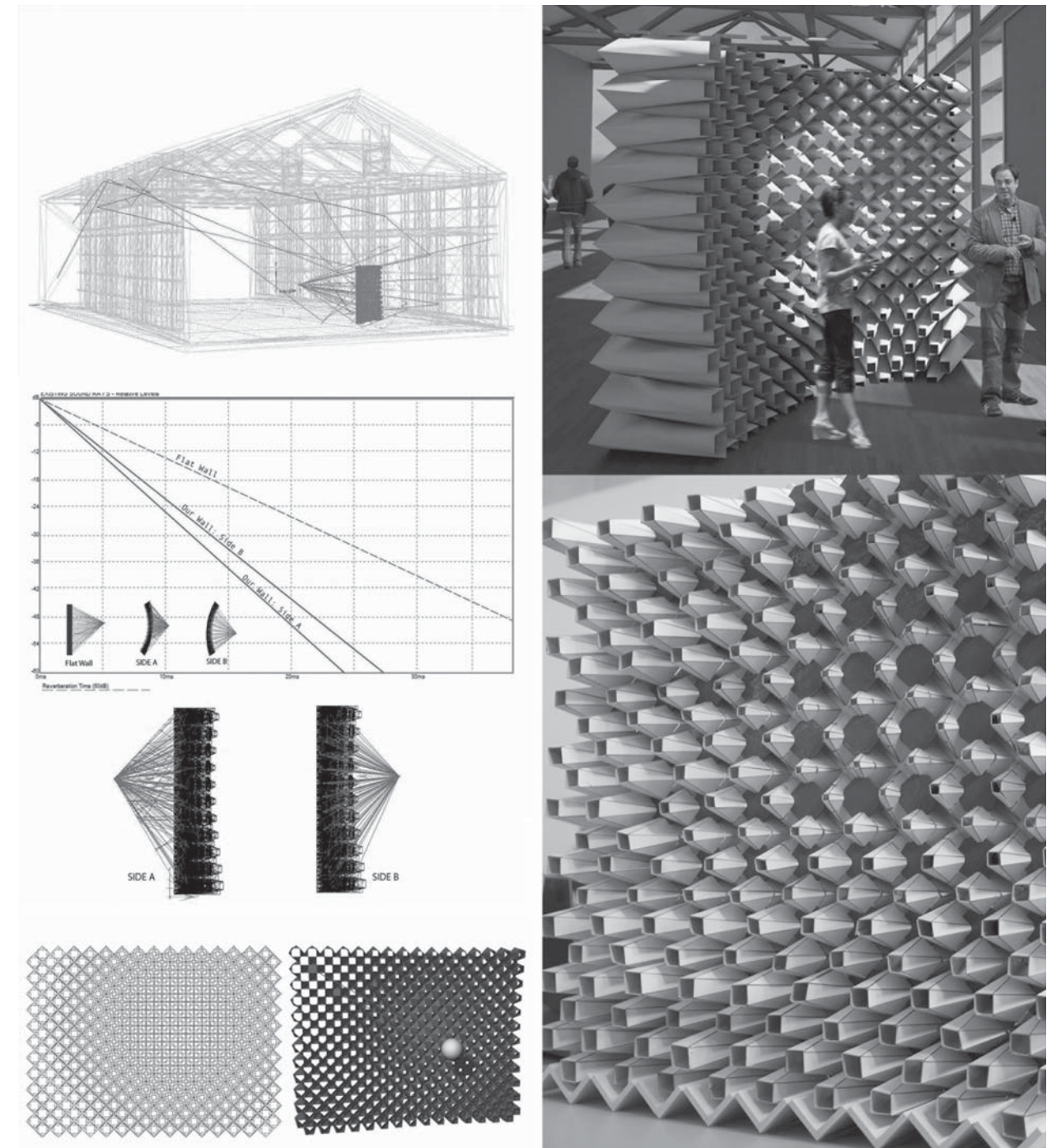


Figure 2
Acoustic wall with 200 adaptive panels.

yield a matrix of adaptive components that acted independently. As a result, we created a high degree of complexity and explored the ornamental possibilities of building an enclosure with relatively simple image input. For each morphing panel, we first defined parameters to capture the color values embed in a 2D bitmap. By linking the 2D bitmap to each panel's morphing weight, the performance data is integrated into the wall topology. Here, the bitmap lets us easily visualize the interconnection between the original data and the corresponding variations in the wall.

The materialization of environmental data is applied to the wall as two hundred unique panels. As a result, we no longer need to view the wall as the homogenous surface but as direct representations of data generated by various external conditions such as view, acoustics, air dynamics or solar radiation. Meanwhile, these sophisticated ornamental systems have the capabilities to optimize the environmental conditions.

4.2 Mapping Structural Data

In these experiments, surface stress load and deformation became the focus of study. Structural simulation tools such as Karamba and Millipede are used to induce the visualization of stress and deformation. We map the structural data to the correct UV points on a given surface. Through surface tessellation, a space frame system is deployed based on the output values mapped to each surface point. The data is mapped directly from the simulation result to the roof surface and drive its structural details. This process can also be used as a recursive operation over generations to create even more complex ornamental patterns, which present an evolution from Michael Hansmyer's subdivision algorithms (Figure 3).

As Aghaiemeybodi described, the represented data is now fused into one single ornament. "Digital technology, perhaps, enables the production of ornaments that are understood to be not a separate entity from the structure but an inherent part of it. In other words, the representation corresponds to the performative aspects of the structure and vice versa" (Aghaei and Aghaiemeybodi 2012).

5 PHASE 3. CUSTOMIZING TOOL PATHS:

ORNAMENTATION THROUGH FABRICATION

In the previous phase, performance related data can "simultaneously fulfill the technical requirements and aesthetic considerations that make the overall visual appeal of a project unique, potent, and affective" (Aghaei and Aghaiemeybodi 2012). However, in Phase 3, non-performance data purely based on the aesthetic considerations can provide a higher degree of flexibility. In this phase, data simply represents another entity, such as an abstract pattern. Data is then automatically deployed to a given form to create ornamental effects. We studied these conditions using parametric tools in Rhino, Grasshopper, and PowerMILL to design concrete tiles. These tools allowed us to test various advancements in scripting, material knowledge, and machining artifacts. First, the tiles required the use of parametric modeling techniques for the design of 2D

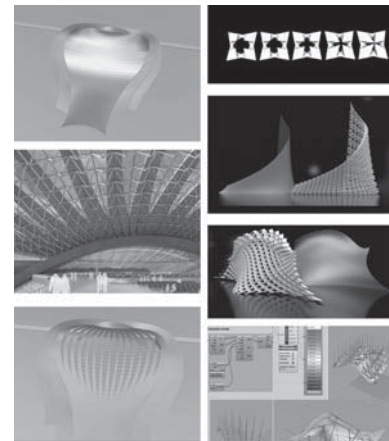


Figure 3
Structural data related to stress, deformation is mapped across the roof surface to drive the thickness and depth of space frames.

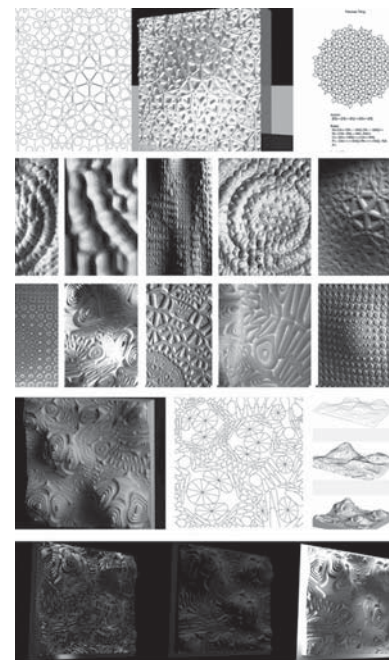


Figure 4
The CNC tool path generated through mathematical patterns and mapped directly onto a surface to produce ornamentation effects.

curves which, based on the surface topography and tessellation, can form a seamless pattern across multiple tiles automatically. We wrote a Grasshopper script that can select a particular mesh face based on its size and orientation and fill it with different "decorative" curves including radial pattern, rings or other mathematical shapes. Similarly to the displacement map in ZBrush and Maya, the abstract 2D curves were then mapped back to a surface as tool paths to generate a sculpted 3D topography. Afterwards, the digital model was routed by a CNC mill as a mother mold and used for mass production in concrete. The milled panel is far more complex compared to the original digital model due to the controlled tool paths and machining artifacts.

The practice of machining artifacts follows the idea of embedding the memory of data mapping and fabrication processes into the built product. The experiment in Phase 3 presents research conducted in customized CNC tool paths to generate complex surface textures that ultimately lead to the definition of a new base material (Figure 4). Based on the original 3D form, a decorative 2D pattern is automatically generated by the Grasshopper script based on aesthetic considerations. The pattern is exported and mapped back to the 3D surface in Rhino. The customized pattern is coded as the tool path in the PowerMILL software and eventually translated into the G code. The machining of the artifact becomes apparent as the unique surface texture is generated. As a result, the machine, not the human, developed emergent patterns from the manufacturing processes. For the designers, the result was unpredictable.

6 PROJECT: THE STRANGE WALL

This three phase method is applied in the recent installation titled "The Strange Wall". Influenced by the concept of the "strange loop" found in music, such as in Bach's canons, the construct curates various artifacts in a cabinet of curiosities with differentiated cubbies to allow for optimum variability. Using CATIA software and Grasshopper scripting, we developed the base unit (vertebrate) through the use of variable subdivision surface to model a cellular structure. In Phase 1, the base unit bred a family of other units through the use of CATIA's parametric tools, such as the incorporation of parameters and equations function of "power copying" instantiation tools (Figure 5).

In Phase 2, the newly transformed units are "power copied" and assembled based on the coordinates associated with each insertion point. A total of sixty-six units with variable input points were instantiated within an armature via a knowledge pattern we developed (meaning "script" using the Product Knowledge Template workbench within CATIA). The script automatically controlled the insertion of each UDF (user-defined-feature). Each UDF morphed function of the knowledge pattern that linked the coordinates for the insertion of the unit to inner parameters controlling the resolution of the initially double curvature, base unit. Because the wall is designed both as an exhibition shelf and a seating platform, the placement of the units is controlled depending on their performance related to these two functions. For example, some smaller double curvature

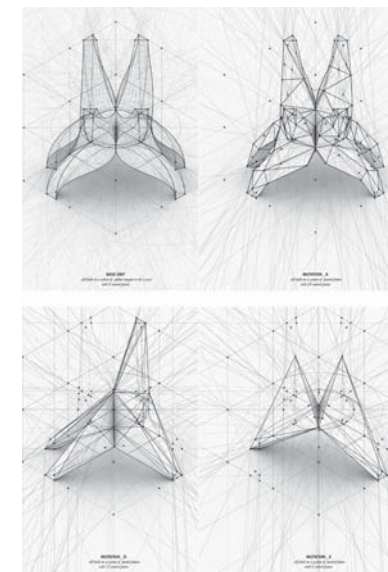


Figure 5
Base unit and subsequent transformations: from vertebrate to its offspring.

units are ideal as cells hosting the displayed objects, while flatter tessellated units are ideal as seating areas, as well as better suited in controlling or framing specific views. As a result, the placement of the sixty-six units is automatically choreographed by the expected functional performance (Figure 6).

In Phase 3, the tool path pattern is automatically conducted by the Grasshopper scripts we developed. The process starts with constructing ornament that grows from the geometric mass. Surface curvatures, face area, and face normal direction are fed into a script. The script can generate various complex curves based on the imported data. In the PowerMILL program, the curves are then mapped onto each surface as tool paths while taking into consideration the accessibility for the three-axis CNC tool head. The optimization process is then applied based on the thickness and step over values mapped to each tool path. The resulting pattern was milled as a customized tool path with within the CNC PowerMILL software (Figure 7).

The machining of the artifact becomes apparent in the unique surface texture. This method develops emergent patterns from the manufacturing processes. The unique surface tessellation and normal data are successfully represented with ornamental quality. The inherent double entendre of ornament as having both functions and affect calls for an open ended dialogue on the un-trivialization of the concept and anticipates larger forms of interaction between the inhabited and the uninhabitable in the Anthropocene. "The Strange Wall" positions itself between following the constraints of fabricating a undevelopable surface assembly on a three-axis router and surrendering the process to the limitations of the fabrication tool while embracing the unexpected undercuts resulting from using more accurate step-overs and a stratified slicing strategy. Designed with the CATIA design development environment, Rhino, and PowerMILL software, this installation pushes a three-axis router to its limits with a unique undercut and variable modules. Eight sheets of high-density foam were flip-milled and joined with a two-part epoxy adhesive to create the final product. Following assemblage, the installation was coated with thin layers of latex primer and metallic paint to enhance its durability (Figure 8).

7 DISCUSSION

In the traditional process, the design approach can become highly abstracted and remains subjective based on designers' preferences. It usually puts the design in a position where performative analysis takes place only after the design process, leaving much of the considerations to the engineer and fabricator. Craft, on the other hand, inherently takes into account material knowledge and construction limits in processes of design generation. We believe that "data mapping", as a new hybrid approach, is forcing designers to consider data driven processes and fabrication technologies to inform a new type of ornament.

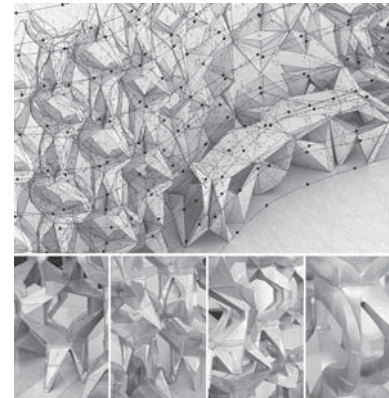


Figure 6
Instantiation within an armature via a knowledge pattern using variable control points.

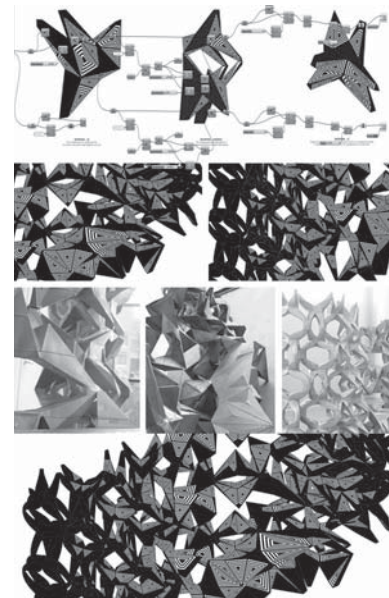


Figure 7
Top: Mapping the tool path pattern function of surface curvature and normal forces. Middle: The Strange Wall, with CNC tool path mapping. Bottom: Customization of CNC tool paths to generate complex surface texture as a deductive process.

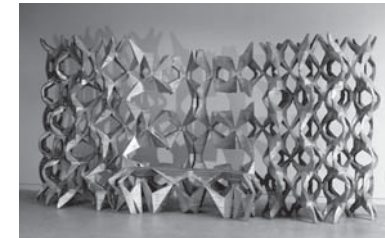


Figure 8
Strange wall, final installation

New architectural morphologies are the result of emerging generative/parametric design tools, which can be realized through advanced manufacturing technologies. Powerful parametric tools such as CATIA and Grasshopper can be used to produce variations in design while maintaining the dependencies and relations between "vertebrate" and its "offspring". Performance-driven design, environment analysis, structure analyses can be used by architects to analyze and optimize design solutions using parameters entry early in the design phase. Removing subjectivity from the design and fabrication process allows for isolating a set of specific constraints and for optimizing the artifact function of that isolated consideration. On the other hand, the non-performance and purely subjective approach allows for filtering the outcome of the performance driven methods holistically and function of each other.

This ongoing research aims to mature tri-part workflow for the subsequent development of ornamentation in architecture. While the data mapping method developed in this paper is limited to the steps outlined above, it is perhaps relevant to understand this method as describing a determined and necessary trajectory as opposed to a fixed state. Consequently, the data mapping method would need to be constantly recalibrated based on the specificity of each project. Its most important outcome is a revival of the process as a product from a craftsmanship perspective. Possible avenues for further inquiry include reflecting on the impact of the process registered in the final product in ways only made possible through the use of computational tools and associated digital fabrication.

The experimental design and fabrication exercises elucidated relationships between matter, form, and structure. There is potential for a reintegration of processes in design generation and mass customization; a reemergence of the architect as a programmer, data analyst, maker, and craftsman. These research projects explore the convergence of function and ornamentation, and their impact on the process of data driven design. The ornament was accomplished through the exploration of several materialization techniques based on performance related data (environmental, structural) and non-performance related data (purely aesthetics).

Today, we can see a much more data driven process influencing the design decision making. Consequently, instead of using form as the center, data mapping has taught us to specify the process of creation first, before defining the multiplicity of elements and local manipulations that will determine the outcome of formal elements. Here, the formal order of components is decentralized from the predetermined form and exclusively ordered through its relation with the process of mapping various essential data. Within the technique of data mapping, the ornament is now understood as a result of integrating overlaid data, whether it is performance related or not, through a hybrid fabrication process.

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His research includes parametric design, digital fabrication, building information modeling, virtual reality, human-computer interaction (HCI), and performance-driven design. His book, *Parametric Building Design* with Autodesk Maya was published by Routledge in 2014.