PARA-Typing Informing Form and the Making of Difference

Digital Design Pedagogy for the Prototyping of Performance and Material Affect

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Abstract

This paper presents design research and instruction into the use of constraint based digital and analogue modelling techniques and the development of associative parametric models to simulate highly differentiated fabricated form. One set of these design research projects were conceived as manual analogue generative processes for prototyping modularity and serial differentiation. Then through parametric design techniques, modular aggregations were design explored and developed in concert with material properties and constraints. Utilizing digital fabrication full-scale installations were designed, manufactured, and for site-specific configurations. A second set of projects provides an extension of the design instruction that includes the integration of performance criteria into these design objectives. The objectives of the research are to present benefits and limitations of the incorporation of parametric design, performance analysis, and prototyping techniques in comprehensive studio instruction. The paper discusses the resultant informed materialized difference and the impacts on achieving reinforced and hands on learning objectives.

Keywords. Generative design; parametric modelling; prototyping; digital fabrication; design pedagogy; performative design.
1. INTRODUCTION

The paper presents an evolution of graduate architecture studio based design research and instructional approach. First, the paper describes the development of projects that moved from analogue and material based form finding to digital simulation, aggregation and fabrication, and back to analogue prototyping at scale. Second, the paper describes a set of design research projects that move from abstract performative pavilions into comprehensive architectural projects and building envelope designs. In the first case the work begins with an initial exploration of patterns and the invention of basic units or modules aggregated into a field that are systematically repeated; our use of the term field stands for an aggregation of units or modules. In the second case the work begins with an initial exploration of pattern and modulation influenced by performance criteria, environmental and tectonic.

Originally an analogue design pedagogy lead the studio to begin to develop modular conditions through examining various origami-like tessellation techniques in the medium of paper prototyping. Similar to the research of Sass [1] there was reliance upon a parametric kit of parts approach albeit analogue in physical material. This process proceeded to a parametric analysis of the basic module and its overall effect on the greater field and the exploring of their capabilities for manipulation and mutation. As a bottom up approach, rules were then applied to the module and its relation to its adjacent neighbors as well as its relation to an overall field being created. As a conclusion to these initial steps of investigation, four modular fields were selected to undergo another series of examinations and developments both through analogue means with the continuation of paper prototyping as well as with the use of digital tools to begin to generate differentiation in the field through the use of parametric computation. With the use of digital fabrication methods four full-scale installations were constructed out of 2-ply chipboard to create spatial apparatuses that defined site-specific spaces. These explorations were an in depth analysis of paper and its tendencies under various stresses, and of the pushing the paper to its structural limits once the installations were assembled in their final configuration. The research presents the experiences and lessons learned for teaching design exploration processes and paralleling digital and analogue techniques in pursuit of making highly differentiated form.

Secondarily the design research presents the results of a two-part studio pedagogy combining parametric modeling with simulation and analysis and material prototyping. The work progresses first through a short three-week exercise to develop strategies for defining performance and for articulating a tectonic assembly where informing the form with rationalized differentiation is the objective. Here, the development of PARA-Typing has the added constraint of performance criteria such as optimizing daylight capture while reducing solar gain in concert with a sense for informing the
making of difference. Then in the remaining twelve weeks the design of comprehensive studio projects is pursued through similar digital and analogue design approaches though made more complicated by increases in program requirements, architectural systems, scale, parameter coupling and number of subjective and objective functions. For the comprehensive design studio the program brief provided was a mixed use building for the fictitious XYZ talent agency, i.e. an office building, mixed with sport and night club facilities appropriate for the Sunset Strip in Los Angeles. As with the first PARA-Typing iteration, of importance to the research was the development of parametric models that drive physical prototyping and digital fabrication models. These designs are then analyzed for the performance criteria established by the studio and each student and then iterated upon before being fabricated and prototyped from these digital models. Here materiality was not only researched for its structural properties as in the first projects but as well for its effect on the architectural conditioning of space and for its potential for the making of difference in an informed manner similar to the work of Hensel [2].

The research presents the successes and limitations of the resulting interface between analogue fabrication and construction process with those of digital abstraction and solution space forming and design exploration [3]. The projects in aggregate enumerate unique design research and teaching methods allowing the constraints of material and of performance criteria to inform digital process and modelling of material connection, tolerance, structural performance, and the parametric-prototyping or “PARA-Typing” of performance and material affect. The paper discusses the effect of parametric modelling and rapid prototyping as a studio based teaching methodology, emphasizing student-learning objectives to promote the materialising of difference and tectonically realized architectural systems that can be more intelligently tuned to perform more complexly. The benefits and limitations of PARA-Typing’s objective, to provide reinforced learning of the value of parametric design, tightly coupled with prototyping material investigation and performance evaluation, for understanding and gaining control of the making of difference is presented.

2. PROJECT MOTIVATIONS AND PRECEDENTS

A primary motivation of the work is that of providing students with a more in-depth facility with the use of parametric design and prototyping technologies in a coupled and feedback fashion in order to meet the needs of contemporary practices. Another primary motivation of the work is to provide students with an in depth experience for inventing systems of material difference and for creating heterogeneous spaces which they can then argue for and validate as performing. The theoretical pedagogical emphasis is on a reinforced and tangible experience with post-fordism and the ability to productively challenge modernism and its anonymization of the
individual and its homogeneity as discussed by Schumacher [4]. Lastly, the informing of form through readily accessible design and computation and prototyping technologies and the notion of the PARA-Type motivates this design research [5].

Our design research builds upon four areas of precedent research, parametric design, prototyping and pedagogy, performance and design integration, and materiality and computing. Parametric design enables quick modifications to design solutions through associative geometry [6]. It is also a successful method used to teach design strategies for integrating domains such as structural design problems as described in references [7, 8, and 9]. A complex model designed in a parametric software can be realized by computer aided fabrication and precise assembly of structural components. [10,1] Problem descriptions developed with parametric design require construction of rapid prototypes in the early design stage [11], made more true in a rapid paced design studio schedule. Digital fabrication technologies entail going from CAD/CAM models to precise 3D manufacturing of components or prototypes by computer-controlled machinery. Rapid prototyping allows fabrication of complex physical models in the product development stage for hands-on learning of building structure described by Sass and Oxman. [12,13] Furthermore, rapid prototyped models can be used to study material characteristics, assembly process, and fabrication flow purposes. [14] The hands on learning of parametric design and the rapid incorporation of material and assembly processes are of particular interest in concert with newfound means for design integration and performance criteria. [15]

A designer has to evaluate the material system in computational models by considering its material characteristics, geometric behaviour, manufacturing constraints and assembly logics in order to understand the complex relations between form, material and structure. [16, 17] Material exploration, modelling and analyzing non-uniform elements structurally are essential to deriving an architectural idea. [18] Understanding the material properties in such a design project is useful in a learning environment as it helps students to understand the sensibility between analogue material systems and digital precision. [19] It is in developing these sensibilities for student understanding of computational precision and material tolerance and in coupling these with environmental performance that our work aims to contribute to novel instruction. Digital Fabrication in a classroom environment also has pedagogical benefits through materialization of concept and interaction with physical artefacts. [20] The design process of translating CAD/CAM models into full-scale construction familiarizes students with rapid-prototyping equipment and precision cutting tools by introducing them to machine shop environments and fabrication related performance. [21] This research builds upon the precedents enumerated as well as identifies a gap and the prevalent instructional limitations in going
from digital design to analogue fabrication in a comprehensive studio environment.

The coupling of design computing with material computation is also a goal of our evolving pedagogical approach similarly to precedents, like those of Burry. [22] However, our design research projects and instruction offer a different set of challenges to be met, those of the NAAB accredited comprehensive design studio. In other words these design researches are occurring in the pursuit of the design and description of architectural projects that must achieve a high level of detail and resolution of numerous practical aspects of architectural design; including for example, egress and fire safety, program and zoning, mechanical systems, parking, and accessibility. Therefore the motivations and evolution of PARA-Typing must be understood through a lens of comprehensive design studio constraints.

3. INSTRUCTIONAL STEPS

The research presents an evolution of studio based pedagogy and methodology from, an initial paper constrained parametric design to fabrication approach, to that of the investigation of performance driven constraints integrated into the design of building envelope systems and buildings. Emphasis is placed on the development of parametric design logics and models for design exploring that enable tunable fields of geometrically differentiated material systems. Throughout, the incorporation of prototyping, rapid and non, is used to enhance the hands on learning of the constraints and economy of material, and time for managing design complexity under these tectonic and performance constraints.

3.1. PARA-Typing full scale fields

The design intent of this first project series, the materializing of difference through the constraints of the paper, undertook multiple techniques and approaches by each of the four student groups. The initial investigations by each of the four groups were strictly an analogue process of repeated experiments of constructing varying modules through paper prototyping. With the basic modules studied and developed, the choice to transition into a digital interface was undertaken to begin to create parametrically driven surfaces that would generate deformation within the module and within the field. Materializing difference was discussed in both the top down and bottom up means, where top down was the driving surface contextualized to a site condition and bottom up was the modulation possible given material and assembly constraints embedded in the modules. At this stage in the project various computational tools were used including Rhinoceros, Grasshopper, RhinoScript, and Digital Project to construct parametric systems, which instigated variance within both the modules (bottom up) and fields (top down). No single parametric design platform was privileged as we
expected to learn from successes, failures, and limitations experienced across the groups.

Based on analysis of a specific site condition, each group developed a parametric surface for design exploring the patterning and control in form finding difference. Then the process of digital fabrication was undertaken to disassemble the various components of each system to be sequentially labelled with its reference to its context within the field as well as its connection to its adjacent neighbouring modules. Then the process of unfolding allowed the individual groups to systematically order the parts in a manner that would allow an efficient reconstruction of the disassembled members. With the use of other programs such as AutoCAD and RhinoNest, a plugin component of Rhinoceros, laser cut files were created for the final part of the digital fabrication process. The benefits of utilizing RhinoNest allowed for the teams to create more optimum layouts for the numerous pieces to reduce the amount of wasted material as well as time it would require to nest manually and to fabricate. Once the digital elements of the project were complete the last stage was to revert back to an analogue procedure and organize the components of each project and assemble the full-scale apparatus to its site-specific configuration.

3.2. PARA-Typing performative envelopes

The second set of projects follow a studio pedagogy where two groups of fourteen students over two years, are asked to work individually on two projects over the course of fifteen weeks. As a starting point students are asked to develop first an abstract performative pavilion on a generic plot with a given sun and wind orientation that is intentionally small in scale and scope. (See Figures 6 and 7) The studio then takes lessons learned from these short duration projects into the development of a comprehensive design studio project, i.e. a mixed use medium rise hybrid office building with a specific site condition. (See Figures 8 and 9)

In contrast to the previous series these students were not asked to form paper or card based material modules but were asked to establish individual definitions of performance and response to environmental performance as starting points for the development of parametric design models and the design exploration process. As with the previous series no single platform was mandated and students developed strategies incorporating Rhino, Grasshopper, Rhino-scripting, Maya, T-Splines, Ecotect, and Digital Project. They then were asked to develop physical models through digital fabrication models using the laser cutters, CNC milling and or the use of rapid 3D prototyping either on FDM or starch based machines.

These initial designs were then critiqued for their success or failure across multiple domain objectives; including structural logic, environmental logic, material and assembly, differentiation logics and aesthetics- informing
form and the making of difference. Discussions of their pavilion systems’ ability to scale and perform as defined by both the instructor and the student were then brought to bear upon the studio’s full brief project. Some students brought forward their pavilion design systems while others did not. However in both cases parametric geometry and materializing difference through PARA-Typing environmental and social performance were lessons brought forward.

The comprehensive design studio project was conducted in a normative fashion. The emphases placed on the use of design and computation approaches to manage and derive complexity driven by imposed and self established performance goals with the use of prototyping technology are the notable pedagogical differences between the first set and the second.

4. PROJECT DESCRIPTIONS AND RESULTS

The following section describes in detail four group design research projects from the PARA-Typing Full Scale Fields series as well as a selection of projects from two years of the PARA-Typing Performative Envelopes series.

In the first series, groups 1, 3, and 4 had three students while group 2 had four. Each followed the general project process described above and each design explored and developed analogue to digital back to analogue techniques. The project descriptions recount modular development, field development, fabrication, and construction sequences.

In the second PARA-Typing Performative Envelopes series, each individual student developed a pavilion and a building project. Each individual student followed the same course brief and outline and incorporated parametric modelling, analysis, physical prototyping, back to comprehensive building design parametric modelling, analysis and prototyping again. The project descriptions recount the pavilion design and the mid rise mixed use building design through an emphasis on design methods, performance and physical prototyping.

Figure 1. Analogue Module Development; a) Group 1; b) Group 2; c) Group 3; d) Group 4.
4.1. PARA-Typing Full Scale Fields Module development and aggregation (analogue)

All groups began module development by experimenting on a piece of paper. Initial tests involved folding, cutting and creasing to create a module for structural investigation such as rigidity and conformity to curvature (Figure 1). Here, a 2D piece is transformed into a 3D rigid material by using the elasticity of the paper. Groups experimented on modules taking into consideration the field creation. Paper prototyping not only teaches students about module differentiation and transformation but also forces them to figure out how to combine the modules through either face-to-face connections or joints that would allow modules to aggregate and form complex structures. The analogue aggregated modules and field development are shown in Figure 2.

4.2. PARA-Typing Full Scale Fields field development (digital)

Digital field development was started by using a parametric design tool (Gehry Technology’s Digital Project) as shown in Figure 3. The modules are instantiated across a context surface simulating the site where their mutations become apparent in their need to stretch and conform to their adjacent neighbours. Using a parametric tool allowed the groups to determine the manufacturability and adaptability of their designs by creating different context shapes. Students also improved their ability to use a parametric tool, and their understanding of how to create conditions where pieces are not skewed beyond the point in which they were designed to function and be buildable.

Figure 2. Analogue Module Aggregation, Field Development: a) Group 1; b) Group 2; c) Group 3; d) Group 4.
All groups visualized their designs in 3D for observation of possible problems. Groups 1 and 2 fixed their context files in problem areas to resolve unwanted deformations. Group 3 and 4 had to re-create other context files in order to finalize their field design. Group 4 switched to Rhinoceros due to not being able to embed the intelligence of the elasticity of the paper within the Digital Project with the knowledge they had. Group 4 also had to create a secondary structure to support their field due to non-rigid connections between the modules.

4.3 PARA-Typing Full Scale Fields fabrication (digital)

Each group used AutoCAD and Rhinoceros to organize and layout 2D flattened individual components translated from 3D configurations to be manufactured by laser cutting tools. Rhinoceros allowed for efficient layout on the sheet material, 2ply chipboard. The laser cut pieces were grouped and labeled for further identification during construction process.

4.4 PARA-Typing Full Scale Fields Pre-fabrication, construction and erection (analogue)

Each group followed a similar process for the pre-fabrication and off-site assembly and then on-site erection. Groups divided the full construction of the installation into manageable sections and assembled in the studio, i.e. pre-fabricated or pre-assembled (Figure 4).

The first group, beginning with the base of the installation and building vertically, experienced the structural integrity of the 2-ply chipboard began to become compromised from the dead weight of the installation (Figure 5a). Group 2 immediately realized in the construction phase the need for a secondary structural system to help support the field in its proposed

![Figure 3. Digital Module Aggregation “fields” and Design Exploration: a) Group 1; b) Group 2; c) Group 3; d) Group 4.](image-url)
These unforeseen problems and failures in the installation did not allow the group to fully assemble their project in its entirety on site yet they were able to achieve an extremely differentiated surface (Figure 5b). For Group 3, construction proved to be challenging due to stress on material and joints created by wind and gravity, another unforeseen in the digital process. Once assembled on the ground the designed differentiation could be experienced successfully throughout the constructed portions of the field (Figure 5c). For group 4, one drawback of the construction was the manual doweling developed to accommodate for the curvature of the field. The need to connect the modules into a full field together was achieved by hanging each piece in its rough orientation on an existing hyperbolic net and then manually connecting each piece together (Figure 5d). With the use of high strength wire the apparatus was suspended from the net, utilizing the gusset plates as the main connection to the existing net condition.
4.5. PARA-Typing Full Scale Fields Results and analysis

For all four groups there were unforeseen failures, which enhanced the hands on learning and reinforced the desired feedback between digital and analogue processes. In all cases, the limitation of the 2ply chipboard to carry its own self weight proved the greatest and most obvious failure. Every group experienced deformation and buckling in the bottom layers due to extensive amounts of stress upon the non-rigid 2ply chipboard. Another second common cause for failure was the lack of simulation and anticipation of the tolerances and forces incurred and needing to be managed on site. In other words the full implementations were not designed to accommodate real world deviations from a perfect Cartesian space as similarly found in Sass’s and Cabrinha’s work. Although students understood the geometrical behaviour of the designed structure, lacking simulation of material and structural behaviour in the computational models led to these failures precedent in the work by Menges. [17] Groups also were not able to easily update their designs once failures were observed due to the individual components being geometrically unique, and when in the scaled analogue mode the modules were no longer variable. In essence the students learned the major limitation of parametric design once working with material systems namely each component in a parametric design has unique geometry, and cannot be merged into a new component and are not usable by other physical models. [20] In contrast to failures, a success for each group was in the earlier paper prototyping stages and the development of structural depth, through curvature, folding and creasing, and joints and aggregation methods to garner structural rigidity; in a hands on reinforced fashion through both analogue and digital means.

Figure 6. 9 pavilions illustrating high degrees of field and module differentiation achieved through parametric modelling and scaled prototyping. All the projects included a focus on environmentally conditioning of interior and exterior spaces through orientation and differentiated openings and clustering of material.
4.6. PARA-Typing performance in Pavilions

This graduate studio pavilion exercise included as in the first series structure and material design exploration then additionally environmental performance driving the informing of form and the making of difference. The work resulted in a variety of design strategies with different emphases on light and shadow and on wind and program. In all cases a scaled model was prototyped from the parametric design exploration and the iterative analysis of building performance analyzed primarily in Ecotect. The parametric design process as before included use of Rhino and Grasshopper, Rhino-Scripting, and Digital Project. From the initial digital design definition and analysis stage students experienced the difficulties in building a scaled model with high degrees of module variation and therefore gained immediate understanding of the value of parametric design to digital fabrication and prototyping. The challenge was accentuated by being forced to demonstrate a measurable and experiential validation of their driving performance objective, typically through visualized maps of heat and light and through photography of shadow casting. Figure 6 shows a subset of the pavilions all of which achieve the materializing of difference objective and some of which achieve successful approaches towards shading and light for example. Figure 7 below is an example project which demonstrates a very clear understanding of the identical topology of the parametric modeling yet enabling extreme geometric difference of each component while incorporating a tolerance and assembly system and satisfying environmental-shading and light filtering and programming- objectives successfully.

![Figure 7](image-url) The image illustrates the full field condition, an assembly mock up of 7 unique modules and then a selection of 3 geometrically unique but topologically identical modules. The series of images illustrate the geometric, material and environmental goals achieved; the parametric modeling and linked rapid prototyping inclusive of generic off the shelf assembly technology, screws and nuts. USC Student R. Brown.

4.7. PARA-TYPING PERFORMANCE IN ENVELOPES

Once the pavilions have been designed, prototyped and critiqued the students then brought these lessons learned into the comprehensive building design. As with the previous experimental project, performance was mandated to be inclusive of two primary design objectives: 1) that of the experiential and visual, i.e. geometric to meet the design research agenda, the context and program opportunities; and 2) that of the environmental performance as it aligned and was in conflict with the experiential and geometric goals. Similar to the previous full-scale field project series was
development of concepts for exterior envelope field modularity. This often came from the initial pavilion design though sometimes students decided to start anew. The use of digital tools included Rhino, Grasshopper, Rhino-Scripting, Maya, and Digital Project. The projects had to adhere to delivering a comprehensive set of architectural solutions as can be seen in Figure 8. So while geometric intricacy tuned for orientation and internally differentiated programs had to influence the envelope design and geometry, students also had to focus on a series of systems that are often not well integrated and correlated into parametric design and prototyping within the constraints and instructional challenges of the NAAB comprehensive studio. These included issues of urban flow and access, program distribution, multi-tenant public and private circulation, accessibility, egress, structural systems, mechanical systems and climate and orientation, and finally envelope zoning and rules of differentiation. (See Figure 8)

5. PARA-TYPING AND PERFORMANCE

With the addition of the dual definition of performance the digital to analogue feedback workflow proved to offer additional results from which an expanded set of conclusions can be drawn. The projects in the comprehensive design studio achieved a high degree of geometric articulation and modulation and the students began to inform these designs with strategies for integrating performance in environmental terms as well as meeting the overall agenda for informing form and the materializing of difference. (See Figures 7, 8 and 9) Successes included students building facility with parametric design environments coupled with environmental analysis tools. The predominant environmental analysis system used was that of Ecotect and some projects with direct integration into grasshopper and or rhino scripting. For all students the use of rapid prototyping technologies, predominantly FDM for the buildings, was also successfully implemented. In the case of the pavilions many students also used laser cutting and or starch based printing. These successes in and of themselves do not constitute novel research, however in the context of comprehensive studio pedagogy we believe are exemplary and unique and offer significant

Figure 8. The figure illustrates 8 comprehensive building design categories and diagrams, a final visualization and a final physical prototype. Illustrative of the complex integration of the building design requirements into a focus on the modeling of the envelopes’ differentiated and informed form and geometry. USC Student A. Malmedal.
lessons learned for others to duplicate as highlighted in the following section.

While the coupling of the parametric and analysis models to that of the prototyping was achieved and lessons were learned there are a number of failures or limitations to be presented. From the first series to the second there are differences in the learning that occurs with predominantly laser cutting and flat sheet material to those of the 3D printing. It is evident the 3D printing does not teach the lessons of economy of flat sheet material nor does the 3D printing provide the tangible experience with structure defined through aggregation and curvature inherent in the modularity. But in the second series both technologies were in fact used and the ability to integrate the additional steps for environmental analysis were in part enabled by the time saved from manual model making due to the automation of the 3D printing.

What is still a major concern is that of the use of these rapid prototypes as final presentation models. Unlike the intended purposes of rapid prototyping, iterating through multiple 3D models most of the students given financial and time limitations end up with a model that has less level of detail then their final digital model and drawings for the final presentation. The reason for this is due to the tolerance of the FDM printing and the scale of the model mostly dictated by cost and time. The result of these constraints produces 3D printed models that are diagrams of the primary structural systems and the often-thickened envelope system is reduced in detail at this scale. While the envelope system does maintain clear levels of differentiation and in some cases successful integration with the other building systems students spend time over scaling and simplifying details so as to make well formed prints. The making of difference is successful from a low level of detail point of view but not always in terms of the learning of assembly, joints, and tolerances.

The informing of form through purposeful integration of environmental conditions was also not an even success across students in the studios. While some projects are extremely well integrated others are not. Some of the envelope designs integrated passive and operable systems conducive to the southern California climate others students ended up with a focus on geometry in worst cases post-rationalized as a screen and percentage of blocked direct light. The most successful student projects did in fact integrate mechanical system with envelope geometry and differentiation and did so through parametric design exploring through linking of Grasshopper and Ecotect.
6. CONCLUSIONS AND DISCUSSION

PARA-Typing performance and the materializing of difference is an architectural instructional agenda that seeks to more tightly couple digital design exploration with material based prototyping. It is conclusively a work in progress within the context of the comprehensive design studio complexities and in comparison to our precedents Burry, Menges, Oxman and Sass to name but a few. On a theoretical level, students are provoked to re-consider modernism and taylorism and in so doing to gain facility with and for the making of tuned heterogeneous space and material systems. On the technical level, the focus of the work has been twofold; 1) to empower students to design with control and mastery of parametric design and prototyping, and 2) to develop discourse that furthers the coupling of these technologies with performance criteria within the context of the comprehensive design studio.

Again the challenges we continue to address in our studios are complex in that there are expectations of meeting comprehensive building design requirements and integrations, i.e. codes, and building physics. Yet given these constraints the additional focus on materializing difference through parametric and digital prototyping has heightened the learning and retention of these post-fordist opportunities something of importance and prevalence in contemporary professional practice.
While there are evident successes in the design and prototyping of complex geometries many of which are directly informed by tectonics, assembly logics and the environmental correlations of site climate and mechanical systems, the ambition of the instructor and learning objectives set up for the students is for them to achieve more intelligent integration of material computing and performance criteria. Through further research and systems integration the studio will continue to develop parametric models where material parameters and assembly logics are more complexly correlated with these performance criteria and building systems. Another critical lesson learned from the evolution of the work is that of the economy required for both design and physical modeling phases for materializing difference in comprehensive architectural design. Often we see the reduction of project complexity in the studio given a students’ inability to conceive of how to manage this complexity under the typical studio based time constraints. Most poignantly this reduction is alleviated and more so complexity is further embraced through the PARA-Typing methodology. We see this as a significant benefit of our approach and one that is again of importance for our graduates to meet the demands of contemporary professional practices. This is an important and encouraging finding of the design research, one that supports a continued incorporation and coupling of parametric design exploration, prototyping, and performance based analysis.

Conclusively, teaching through associative parametric design methods helped students to create highly differentiated and fabricated geometries that are informed by material, assembly logics and most recently performance criteria. Without bringing to the students instruction on how to translate their ideas into a parametric design, to prototype, then to analyze in a feedback loop, the projects would have not achieved the degree of material differentiation sought after nor their incorporation of performative results.

Finally, the notion of PARA-Typing is an intentional neologism that addresses the need for bringing associative parametric design, prototyping, and performance analysis technologies and techniques to the comprehensive studio challenges. It does so in support of an increase in materially pre-solved prototypes from which to design explore, providing both more informed form as environmentally conditioned architecture and more geometrically intricate and heterogeneously materialized difference.

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