PARA-TYPING THE MAKING OF DIFFERENCE

Associative parametric design methodologies for teaching the prototyping of material affect

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Abstract. PARA-Typing the Making of Difference 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. These design research projects were conceived as manual analogue generative processes for prototyping modularity and serial differentiation. Then through associative parametric design technologies and methodologies, modular fields were design explored and developed in concert with material properties and constraints. Utilising digital fabrication full-scale installations were designed, manufactured, and constructed as tiled walls that created differentiated space within site-specific configurations.

Keywords. Generative design; parametric modelling; prototyping; digital fabrication; tectonics.

1. Introduction

PARA-Typing presents design research which 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. It begins with an initial exploration of patterns and the invention of basic units or modules aggregated into a field that are systematically repeated. The initial analogue design pedagogy lead the studio to begin to develop modular conditions through examining various origami-like tessellation methods in
the medium of paper prototyping. This process proceeded to a parametric analysis of the basic module and its overall effect on the greater field and the exploring of capabilities of 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. The research discusses the methods of translation of design intent and material affect into digital methods and then back through digital fabrication for analogue material assembly. 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. The projects enumerate unique design research and design teaching methods allowing the constraints of material to inform digital process and prototyping of material connection, tolerance, structural performance, and the parametric-prototyping or PARA-Typing of material affect. The design research discusses prototyping and the effect of parametric modelling as a prototyping methodology with its ability to promote the materialising of difference and tectonically realised architectural systems.

2. Project precedents and motivations

Our design research builds upon three areas of precedent, parametric design, prototyping and pedagogy, and material and computing. Parametric design enables quick modifications to design solutions through associative geometry (Aish and Woodbury 2005). It is also a successful method to teach design strategies about structural design problems (Woodbury et al. 2007, Holzer et al. 2007, Flager et al. 2009). A complex model designed in a parametric software can be realised by computer aided fabrication and precise assembly of structural components (Sass 2009, Fleischmann et al. 2011). Problem descriptions developed with parametric design requires construction of rapid prototypes in
the early design stage (Hudson 2009). 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 (Griffith and Sass 2006, Oxman 2009). Rapid prototyped models can be used to study material characteristics, assembly process, and fabrication flow purposes (Kilian 2003).

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 (Hensel and Menges 2006, Menges 2007). Material exploration, modelling and analysing non-uniform elements structurally are essential to deriving an architectural idea (Iwamoto and Scott 2011). 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 (Cabrinha 2010). Digital Fabrication in a classroom environment also has pedagogical benefits through materialisation of concept and interaction with physical artefacts (Sass and Oxman 2006). The design process of translating CAD/CAM models into full scale construction familiarises students with rapid-prototyping equipment and precision cutting tools by introducing them to machine shop environments (Iwamoto 2004). This research builds upon the precedents enumerated as well as aims to identify the gaps of going from digital design to analogue fabrication in a studio environment.

3. Project methodology

Given the design intent of the course project, the materialising of difference and the constraints of the paper multiple methodologies and approaches were undertaken by each of the four student groups. The initial investigations done 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. 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 the modules and fields. The digital phase of the project included often multiple platforms and varying computational techniques to achieve their own parametrically driven differentiated surfaces.
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 utilising RhinoNest allowed for the program to create the optimum layout for the numerous pieces to reduce the amount of wasted material as well as the time it would require to nest manually. Once the digital elements of the project were complete the last stage was to revert back to an analogue procedure and organise the numerous components of each project and assemble the full-scale apparatus to its site-specific configuration.

4. Project descriptions and results

The following section describes in detail four group design research methodologies and results. Groups 1, 3, and 4 had three students while group 2 had four. Each followed the general project methodology described above and each design explored and developed unique analogue to digital back to analogue methods. The project descriptions recount modular development, field development, fabrication, and construction sequences.

Figure 1. Analogue Module Development; a) Group 1; b) Group 2; c) Group 3; d) Group 4.
4.1. 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.

![Figure 2. Analogue Module Aggregation, Field Development; a) Group 1; b) Group 2; c) Group 3; d) Group 4.](image)

4.2. 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.
All groups visualised 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 finalise 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.

Figure 3. Digital Module Aggregation and Design Exploration:
   a) Group 1; b) Group 2; c) Group 3; d) Group 4.

4.3. FABRICATION (DIGITAL)

Each group used AutoCAD and Rhinonest to organise and layout 2D flattened individual components translated from 3D configurations to be manufactured by laser cutting tools. Rhinonest allowed for efficient layout on the sheet material, 2-ply chipboard. The laser cut pieces were grouped and labelled for further identification during construction process. The distinct size and custom nature of each module forced groups to layout different 2D sizes for each component, and use a large amount of construction material.

4.4. 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. Once the full complement of flat sheet pieces were cut the assembly of each module could begin. Groups divided the full construction of the installation into manageable sections and assembled in the studio, i.e. pre-fabricated (Figure 4).

The first group took the corresponding pieces and folding and gluing along designated joints. Beginning with the base of the installation and building vertically the structural integrity of the 2-ply chipboard began to become...
compromised from the dead weight of the installation (Figure 5a). Group 2 immediately realised in the construction phase the need for a secondary structural system to help support the field in its proposed configuration. These unforeseen problems and failures in the installation did not allow the group to fully assemble their project in its entirety on site yet the experimental process at which they were able to achieve throughout the process created an extremely differentiated surface (Figure 5b). As 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. Although it could only be assembled on the ground the designed differentiation could be seen 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. Once each manageable piece was completed the need to fully connect the full field together was needed, this 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 transparent wire the apparatus was suspended from the net, utilising the gusset plates as the main connection to the existing net condition.

The construction process is illustrated in Figure 4. Each group project in various stages of assembly can be seen as the field continues to grow with the addition of each module component: a) Group 1; b) Group 2; c) Group 3; d) Group 4.

4.5. RESULTS AND ANALYSIS

For all four groups there were unforeseen failures. In all cases, the limitation of the 2-ply chipboard to carry its own self weight proved the greatest and most obvious failure. Every group experienced deformation and buckling in the walls of the bottom layers due to extensive amounts of stress upon the non-rigid 2-ply 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 in site. In other words the full implementations were not designed to accommodate real world deviations from a perfect Cartesian space. Although students understood the geometrical behaviour of the designed structure, lacking simulation of material and structural behaviour in the computational model led to these obvious failures similarly to work published by Menges (2007). Groups also were not able to easily update their design when needed due to individual components manufactured being vastly different from each other, once back in the scaled analogue the modules were no longer variable. Since each component in a parametric design has specific geometry, they cannot be merged into a new component and are not usable by other physical models (Sass 2009). In contrast to failures, a success for each student 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.

5. Conclusion

What began as a design study that borrowed from textile and fashion design for inspiring analogue card model unitisation and modularity quickly lead to questions of design iteration, and methods for translation into models for digital fabrication. Given the design intention for the designing and paper prototyping of fields of highly differentiated pattern the projects all arrived at a decision point of how to model digitally, how to incorporate parameters to ensure constructability and of how to tune for managing of continuously dif-
ferentiated modularity, albeit digitally. The teams individually began to move the prototypes into digital simulations and to model associatively and parametrically for means of control and design to fabrication.

A result of the analogue to digital back to analogue process was a realisation of materially based structural performance and the inadequacies of the pursued parametric methods. While the teams achieved successes in their design explorations and iterations, and in their ability to improve upon the control and direct communication to the digital fabrication the projects all suffered from a lack of resolution for incorporating the parameters of the material themselves. The complexity of the geometry was achieved but the encoding of the material stress, strain, and structural failure were not.

One pedagogic goal of the projects was to teach students parametric thinking through rapid prototyping. Rather than going directly from digital design and fabrication to analogue construction process, we intentionally promoted the students’ hands-on form generation (or handcrafting) on paper to engage them in early 3D model development. As a result students began to anticipate the possible problems at a very early stage. They then represented and developed their analogue model in a parametric digital tool environment that helped them understand how to avoid design forms that are not manufacturable. The parametric modelling also helped groups to figure out the assembly process and fabrication sequence of their highly differentiated surface tiling. Students were able to observe the gap between computer representations and full-scale construction tangibly. CAD/CAM model translation and digital fabrication by precision laser cutting introduced students to the world of machining, shop drawings and proper cutting techniques. Students, however, were not given the opportunity to choose or search for a construction material. They were also not able to test their work before full-scale laser cutting due to limitations of class time. We believe material failures could be overcome through more prototyping and initial testing with their design.

Teaching through associative parametric methods also helped students’ ability to create highly differentiated and fabricated geometries. Students were able to materialise their concepts from scratch and achieve learning by doing. The projects do contribute to the contemporary discourse of teaching through associative parametric methods in that they clearly demonstrate the capabilities and design methodology enhancements from the pedagogical and design research aspects, as seen through the vast amount of differentiated and fabricated geometries. Without the workshop and bringing to the teams the ability to parametrically and logically describe, and translate their ideas into a parametric design system the projects would have not achieved the degree of differentiation and the making of difference sought after. Here the notion
of PARA-Typing is an intentional neologism which speaks to the need for bringing associative parametric design technologies and methodologies to the studio problems as well as to the validated strength of the process, that of an increased solution space forming and by virtue an increase in materially presolved prototypes albeit partially form from which to choose.

References