Parametric: Making

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Digital fabrication has stimulated the return of the architect as builder over the past fifteen years or so and projects are showing up all over which implement these tools as a major design factor. More recently, parametrics has become a buzzword as its being used to design structures that respond to their environment and other site conditions. While parametrics can be a powerful tool, we rarely see it leave the realm of the design process and venture into the physical world.

Through a project entitled the BENCHES, completed by a digital craft studio at Louisiana Tech University, students applied parametric modeling techniques with a primary focus directed towards the fabrication process. This was executed through three different areas; 1) ‘Back-end Design’ where details were developed and manipulated through a Grasshopper® definition, 2) ‘Statistic Calculations’ where a Microsoft Excel® was dynamically linked to the design model to give live updates on part counts, costs, and feedback information, 3) ‘Fabrication Organization’ which created, labeled, and nested all fabrication drawings.

The result was an extended design phase, lower project cost, and higher productivity. The traditionally linear work-flow model of design, back-end design, production and fabrication was rearranged allowing for several phases to overlap creating a more efficient design process.
Introduction

Like many trends, it seems as if parametrics have taken over discussions within current trajectories of architectural education. It is a rarity for one to make it through an afternoon of reviews and not hear the words “scripted”, “associative”, “programming”, “algorithmic”, or “gerative” used to describe potential design strategies. That is, however, all the further these suggestions tend to employ themselves; delegated to the abstract space that is the design process. But the potentials of such parametric design techniques have tremendous possibilities when it comes to fabrication processes and realization.

Throughout this paper I will use theBENCHES project as a vehicle by which to make an argument for the usage of parametric design techniques within the process of making, as it relates to more efficient workflows. More specifically, parametrics can be used in a manner that will extend the design phase, reduce fabrication preparation time, and lessen project costs. I am also going to discuss the advantages of applying these techniques through three areas in particular; ‘Back-end Design’, ‘Statistic Calculations’, and ‘Fabrication Organization’. It is important to understand that these areas are by no means sequential, but rather interdependent, and modifications to one area impart the other two.

In the fall of 2009, I lead a digital craft studio at Louisiana Tech University that focused on a design-build problem through the use digital fabrication and rapid prototyping methods. While other similar studios design and realize their projects using off-the-shelf parts, the focus on this studio was to design in a way which implemented the digital fabrication equipment in one of two manners; either directly, as a way to produce the parts that become the project, or indirectly, by using the equipment to produce some type of fabricated system which would then create the parts (e.g. jigs or molds).

The program that was used for the studio focused on creating additional seating elements within a courtyard space located in George T. Madison(GTM) Hall. The GTM Hall currently houses the several departments within the College of Liberal Arts, including English, and the courtyard space within GTM Hall is referred to as the Shakespeare Garden (Figure 1). This vacant space has taken on several rennovations over the past several years, which include the covering of an antiquated fountain into a stage for the annual sonnet readings that take place on Shakespeare’s birthday. These types of events often draw far more people than the space can seat comfortably and therein lies the design issue of the studio. It should also be noted that at the beginning of the studio, neither the students nor the instructor had any background in parametric modeling software, but simply the knowledge of its potential applications. It is this initial limitation which became the seed for this paper. We were all still learning the software functionality while the initial design process was underway.

Back-end Design

The first task in within this endeavor is to pinpoint the areas in which parametric modeling can assist in the fabrication process of a project as it attempts to transfer from proposal into constructed object. Branko Kolarevic recognizes this potential within his book *Architecture in the Digital Age: Design and Manufacturing* where he states the following;

This new found ability to generate construction information directly from design information, and not the complex curving forms, is what defines the most profound aspect of much of the contemporary architecture.¹

By integrating the concepts of parametrics into the phase I’m refering to as ‘back-end design’, we will begin the process of producing the necessary construction documents as mentioned above. So what exactly is ‘back-end design’? I equate this term to what my college, Michael Willams, refers to as “design with a lowercase d”², that which supports primary design. While all design decisions at this point are important, the major gestures of the project have been made. Back-end design is about figuring out the details as they manifest themselves in both physical form (how does steel meet
wood?) as well as material properties (how does steel accommodate wood expanding?). Furthermore, back-end design lies the foundation for process as this is where initial ideas of fabrication have their roots.

For the BENCHES, back-end design begun around week six, as the project direction had been chosen and groups united. It was at this point when students took ownership over an aspect of the project and broke into teams that focused on these tasks. While one group continued to work on the formal gesture, which the seating elements would eventually take, another tackled the details of realization and fabrication. Students quickly agreed upon a ‘cat scan’ technique in which sections would be cut along the longitudinal axis of each bench (Figure 2). These sections would be made of laser-cut steel and ‘capped’ with Computer Numerical Controled (CNC) routed cedar, much like the handle of a knife around its blade.

This is where the parametric model began to prove its worth as we made adjustments to these design decisions. The model allowed us to adjust the number of ‘cat scan’ sections as necessary; more sections meant a more accurate form and more comfortable seating, however at the cost of more steel required, more time to cut it, and more weight. A 2” on-center spacing was determined to have the optimal performance criteria to balance comfort, form, cost, time, and weight, as well as allowing for the fabrication process of getting an allen wrench between the sections required to tighten the hardware. The wooden caps had the most dependency upon parametric modeling as it controlled variables such as cap width (cw), cap depth (cd), wrap percentage (wp), break points (bp), bolt locations (bl), bolt size (bs), and bolt-hole shape (circle in wood, oval in steel)(Figure 3). All of these variables were considered as they weighed the advantages of stronger parts against overall design intent, and material properties. It goes without saying that all these variables also impact project costs in one form or another, but we’ll save this discussion for a little later.

Figure 1. Shakespeare Garden – George T. Madison Hall – Louisiana Tech University, 2009

Figure 2. Initial bench form used as prototype for parametric model.
It’s important to note that at this point, formal studies were still being investigated by another group while back-end design decisions were being made. A work-in-progress model was used as a placeholder for generating the parametric Grasshopper® definition. The traditional linear work-flow diagram of front-end design > design > back-end design had been stacked, allowing us to extend the design phase as long as possible, and still complete the project in the allotted 10-week timeframe. Students were able to work on a range of project tasks (throughout various phases) simultaneously due to the parametric model. This increased our efficiency, as students greatly reduced downtime waiting on a phase to complete prior to starting the next task (Figure 4). In practice this translates into saved labor costs.

**Statistic Calculations**

As I previously discussed, all three of these sections should not be seen as a linear progression, but rather as an interconnected system. In the back-end design phase the ‘cat scan’ technique was chosen with the primary variable being the number of sections necessary. It was also mentioned in the project introduction that the BENCHES were to be situated within the courtyard space of GTM Hall. The only means of access was through a series of doors with an opening no wider than 36”. Because of this, no machinery could be used for the installation process. Weight became an issue as all fabricated parts would need to be carried into place. Using the parametric model, students were able to calculate each benches’ total surface area of steel and, in turn, verify the approximate weight of each bench. This information was fed back to the back-end design phase and used to limit the number of allowable sections, while at the same time the surface area calculation was sent out to a powder coater for a quote. These same calculations were used for both internal and external analysis.

Just as the parametric model was able to locate all necessary bolt-holes, both in the steel and wood, it also tallied these openings for a bolt count. Upon multiplying this count by the price per unit and realizing the total hardware cost, it was determined that the initial bolt and nut combination was not going to be financially feasible at the quantities the current design required. A less expensive equivalent part was found; however, this new part had slightly difference dimensions than the original one. These modified dimensions were relayed through the back-end design phase which, as a result, updated all bolt-hole openings.

As the part count grew, it became apparent that Grasshopper® was not going to be the best way to both calculate and manage part statistics and budget information. Microsoft Excel® is a software traditionally left to that of accountants, scientists, and statisticians, however, paired with the right parametric design counterpart, we were able to implement Excel® as a

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**Figure 3.** ‘Back-end Design’ variables within the parametric model

**Figure 4.** Traditional Workflow Diagram vs. Parametric Workflow Diagram
Both Grasshopper® and Excel® work off the same principle, beginning with a component/equation, one adjusts the input, and the resulting output alters. When used in series though, the benefits of each are multiplied.

Using the ‘Stream Contents’ option within Grasshopper®, the totaled part statistics were able to be streamed live as a text document which was imported into Excel®. From there unit costs were input and multiplied by parts needed. We were able to track costs on all aspects of the project from the number of nuts and bolts needed, to calculating the surface area of cedar and, in turn, gallons of sealant needed. As the design changed, so too did the parametric model as well as the dynamic budget spreadsheet.

Unlike so many projects that exist within the abstract world that is studio, this one had a budget to keep which, in itself, became a design factor. Many ideas the students wanted to implement were discarded for this very reason. This process also allowed the students to target areas that resulted in the greatest financial impact, and allowing them to more quickly obtain a design under budget. By connecting these two programs, Grasshopper® and Microsoft Excel®, design decisions were able to be made with cost implication becoming immediately apparent. It also facilitated a dialog between statistic calculations, back-end design, and eventually fabrication organization.

**Fabrication Organization**

To make this next comparison, I would like to introduce you to another project completed by myself, Joe Baker, Matt Plecnic, and Beau Seyerle as graduate students at The Ohio State University in 2006, under the direction of Prof. Steven Turk. The project began when The Ohio State University’s Experimental Media and Movement Arts (EMMA) Lab approached the Knowlton School of Architecture for an installation piece within their performance space. At the time, EMMA Lab was unable to describe what they envisioned as a physical object, but could clearly express the performative features the final design would achieve. Ideas of interaction, display, seating, screening, and movement all became focus topics as the design took form. The end product was the WALLS, a series of laminated plywood screens that were self-supportive, mobile, and versatile enough to be used as props with or backdrop for the performance (Figure 5).

While the designs of these two projects, the WALLS and the BENCHES, by no means are identical. They do however have similar attributes within their respective processes. Both projects had a similar timeframe of approximately 10-weeks, from initial discussions to completion, both projects were of a similar scale and had a similar number students, both projects had similar course construct of small groups generating multiple ideas, and both projects had fabrication methods. The difference in these ventures becomes evident in the final output. The objective of each studio was to produce a process, or set of instructions that could live beyond the life of the studio. This was physically manifested for the BENCHES as three completed seating elements whereas the WALLS were only presented as a partial series of what was to be a larger collection. The reason for the incomplete set of screens was simple, time.
In any project there is a turning point at which design must be severally reduced (as I do not feel design ever truly ceases) and give way to production and fabrication. For both of these projects, this took place with about two weeks remaining in the quarter – one by choice and the other due to circumstances. From the onset of the BENCHES, a schedule was drawn up that consisted of a 7-week design phase, 1-week prototyping phase, and 2-week fabrication phase that was followed fairly tightly. As for the WALLS what was scheduled and followed were two difference entities altogether. What was originally planned to be a four-week fabrication phase, was reduced to just two weeks as discussions with the client extended beyond the allotted design phase. In addition to this, we spent nearly four days producing the fabrication drawings which included section cutting the solid computer model, laying out and labeling all parts, and manually nesting them within our stock. After the set of drawings for each screen were created, we could generate toolpaths and estimate run times to determine the final number of screens we had time to produce. The compromise to the extended design phase and production technique was a reduced number of complete screens within the series.

For the BENCHES we approached the task of fabrication drawings from the onset. Built into the parametric model was the ability to take each section (steel as well as cedar caps), lay them out on a base plane, and sequentially number them according to their bench and location (Figure 6). This alone saved hours. However by implementing RhinoNest, which “…can optimize part position and orientation for a material…”\textsuperscript{3}, efficiencies of material were calculated and applied back into the back-end design phase to save time and costs yet again. Due to the shape of the wooden caps, as well as our choice of cedar boards, it became very inefficient to maintain the wooden caps as one continuous element. Break points were added to optimize nesting capabilities and minimize material use. Ultimately we found that more is not necessarily better. While more pieces allowed for tighter nesting, this graph eventually planes off as more space is needed for part-to-part spacing, eventually creating more void than solid out of the material. In addition, more pieces required additional tracking of parts and increased the potential of human error. The conclusion of two break points (creating 3 parts) per section was determined to be optimal.

My last argument for the application of parametrics within the production phases of this project relates to calculating runtimes of the CNC equipment. For us, analysis of runtimes was an important factor in determining if we had the man- and machine-power to complete this project in the allotted timeframe. Were there enough hours in the day to cut all the steel sections and CNC route the wooden caps? By this point in the design process, we has generated profiles for all the section in need of being cut. After totaling their perimeter lengths, multiplying this by a machine feedrate, and allotting an estimated overage to accommodate for jog times, we were able to get a rough calculation of runtime necessary for each piece of equipment. In our scenario, this amount of time called for outsourcing the laser-cutting of the steel sections to a local factory. This same federate calculation helped determine laser-cutting costs which were then streamed into our Excel\textsuperscript{®} budget for final analysis.

**Summary**

As you can see, the fabrication process was fully dependent upon the parametric model and techniques. Students were challenged with the task of thinking through the fabrication process in conjunction with, not
subsequent to, the boarder design decisions. This application allowed student to extend design time by implementing a parametric model that eliminated busy-work of production drawings, as well as highlighted opportunities for design optimization. ‘Back-end design’ allowed for students to manipulate design details while also producing parts for future fabrication. In ‘Statistical Calculations’ students received dynamic updates on project costs as design modifications were made. ‘Fabrication Organization’ eliminated the chore of file preparations as the combination of the parametric model and RhinoNest accomplished this task. By implementing a parametric model, designers would be able to overlap various phases of the creative process and extend their design time while reducing project costs; and optimize their efficiency.

References

2 Michael Williams, Louisiana Tech University, 2010
3 www.RhinoNest.com

Figure 7.a. Matching existing Shakespeare bust
Figure 7.b. theBENCHES in GTM courtyard space
Figure 7.c. Break points of wooden sections