I, George Faber, hereby submit this original work as part of the requirements for the degree of Master of Architecture in Architecture (Master of).

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DESIGNING DESIGN:
EXPLORING
DIGITAL
WORKFLOWS IN
ARCHITECTURE

A THESIS BY GEORGE FABER
Designing Design: Exploring Digital Workflows in Architecture

A thesis submitted to the Graduate School of the University of Cincinnati in partial fulfillment of the requirements for the degree of Master of Architecture in the School of Architecture and Interior Design of the College of Design, Architecture, Art and Planning

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From the very beginning, the digitization of architecture has concerned itself around the speed of representation. The benefits of CAD drafting software principally relate to its suitability for repetitive work, as it facilitated the use of cut, copy and paste. Now with BIM and other parametric software, changes made to a single drawing are instantaneously updated across the entire drawing set.

By capitalizing on the inherent relationships that can be created between objects, parametric modeling aims to reduce the amount of time editing design elements and thus fulfilling this paradigm of speed. As a result, these tools enable designers to define the constraints around which an object is created rather than designing the object itself. The result of this thinking leads to the creation of a parametric model that embeds design logics into the construction of the digital model.

The focus of this thesis is on imparting an understanding and sensibility to designers of how to use parametric models in a productive way. It attempts to address common misconceptions and known criticisms of this digital workflow.

Through the typology of an indoor rock climbing gym, the purpose of this thesis is to better understand the limitations and constraints of parametric modeling tools. This thesis is about the digital workflows necessary for parametric modeling, which in turn argues for the need for parametric thinking.
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# TABLE OF CONTENTS

0 List of Illustrations
1 Introduction
   1.1 A Topic of Language
   1.2 The Digitalization of Architecture
2 Designing Design
   2.1 Conventional vs. Parametric Models
   2.2 Cost of Change
   2.3 Parametric Thinking
   2.4 Parametric Louvers
   2.5 Design to Fabrication
3 The Shortcomings of Parametric Modeling
   3.1 A Hybrid Designer
   3.2 Designing Flexibility
   3.3 Designing for Unknowns
   3.4 Change Blindness
   3.5 Open Source Code
4 Conclusion
   4.1 Final Thoughts
5 Bibliography
**LIST OF ILLUSTRATIONS**

Fig 0.01
Front cover, edited by author
Photograph by: LaFouche

Fig 1.01
"Introduction" chapter image, edited by author
Photograph by: ICD/ITKE/IIGS University of Stuttgart, James Nebel, Roland Halbe

Fig 1.02
Illustration of a unit circle.
Source: http://en.wikipedia.org/wiki/Unit_circle

Fig 1.03
Sketchpad interface

Fig 1.04
Ivan Sutherland using Sketchpad
Source: https://design.osu.edu/carlson/history/images/pages/ivan-sutherland_jpg.htm

Fig 2.01
"Designing Design" chapter image, edited by author

Fig 2.02
Traditional workflow
Diagram by author

Fig 2.03
Parametric workflow
Diagram by author

Fig 2.04
Boehm curve

Fig 2.05
MacLeamy curve

Fig 2.06
Louver installation
Source: http://shaneburger.com/2011/08/designing-design/

Fig 2.07
Digital workflow
Source: http://shaneburger.com/2011/08/designing-design/

Fig 2.08
Kilden Performing Arts Centre
Source: http://www.designboom.com/architecture/ala-architects-complete-the-kilden-performing-arts-center/

Fig 2.09
Kilden Performing Arts Centre
Source: http://www.designboom.com/architecture/ala-architects-complete-the-kilden-performing-arts-center/

Fig 2.10
View from lobby
Source: http://www.designboom.com/architecture/ala-architects-complete-the-kilden-performing-arts-center/

Fig 2.11
Roof detail
Source: http://www.designboom.com/architecture/ala-architects-complete-the-kilden-performing-arts-center/

Fig 3.01
"Shortcomings of Parametric modeling" chapter image, edited by author

Fig 3.02
Wall Studies
Diagram by author

Fig 3.03
Color Studies
Diagram by author
LIST OF ILLUSTRATIONS (CONT.)

Fig 3.04
Stair Studies
Diagram by author

Fig 3.05
Screenshot from Ming3d.com

Fig. 3.06
Screenshot from Grasshopper3d.com

Fig 4.01
“Conclusions” chapter image, edited by author
Photographer: Hufton + Crow
Source: http://www.archdaily.com/448774/heydar-aliyev-center-zaha-hadid-architects/
1. INTRODUCTION

1.1 A TOPIC OF LANGUAGE
1.2 THE DIGITALIZATION OF ARCHITECTURE
A TOPIC OF LANGUAGE:

A topic of debate in the field of architecture is the term parametric. I have found it is often misunderstood or used in incredibly vague ways. Is parametric an aesthetic style? Because something is “blobby”, does that justify the title? Alternatively, is it a movement, as Patrik Schumacher has suggested and coined parametricism? Some even argue that it has more to do with the software used? This disconnect of meanings illustrates a particular need to clarify the definition I will be using.

The term parametric originates in mathematics and refers to a set of quantities expressed as an explicit function of a number of parameters. An example of a parametric equation is the formula that defines a point on a unit circle:

\[
\begin{align*}
    x &= \cos t \\
    y &= \sin t
\end{align*}
\]

This formula meets two critical requirements to define it as a parametric equation. First, it expresses an output, in this case, values of \( x \) and \( y \) that can be plotted on a graph. Second, the values for \( x \) and \( y \) are related to each other through the explicit functions and the variable \( t \).

In architecture, the term parametric is commonly paired with modeling. Parametric or associative modeling is the “paradigm of programming the definitions of the geometry and their associated relationships so that they might be more easily adjustable by simple algorithmic manipulation and changes can be varied interactively.” As a result, these tools enable designers to define the constraints around which an object is created rather than designing the object itself. In doing so, the designer inherently embeds the logic and intent of the design decisions within the computer model expressed as mathematical equations.

Today, architects can build parametric models in a range of different software. Some use history-based modelers, which store the steps in which an object is created, allowing the designer to make changes later. Examples include Maya, CATIA, and SolidWorks. Others work by using a graphic scripting interface, which often resemble flowcharts or webs. Grasshopper and GenerativeComponents are two popular examples of visual scripting software. Furthermore, there exist textual scripting interfaces within most CAD programs. These allow designers to setup parameters and a set of explicit functions that generate geometry and other parametric outputs.

Software is a continually shifting factor in the realm of digital design. With this in mind, the intent of this thesis is not to explain the technical functioning’s of any particular program but rather to explore the concepts embedded within them. In other words, this is a thesis about parametric thinking; it is about studying a methodology rather than software. The hope is that by removing itself from the program-du-jour, this thesis can prolong its relevancy within this discourse.

THE DIGITALIZATION OF ARCHITECTURE:

In 1963, as part of his doctoral project at MIT, Ivan Sutherland draws on a computer. It becomes the first-time anyone has done so and is seen as the birth of CAD (computer aided drafting). His project, titled Sketchpad, uses “drawing as a novel communication medium for a computer” which enables users to directly create and edit straight lines and circle arcs on a virtual platform. With the use of a “light pen” and various push buttons, users can perform such tasks as copy/paste, erase, and move. Other functions, such as the ability to create groups, or master files, which can be referenced into different drawings are all but commonplace in modern CAD programs. By exploiting the computer’s ability to handle these commands quickly, Sketchpad was intended to reduce the production time of manually re-drawing identical symbols. While Sutherland designed the system to be used to drawing electrical drawings, the application has had a profound impact in the field of architecture. This translation from physical to digital drawings remains critical in the development of countless CAD software, however, the truly innovated accomplishment was that Sketchpad had the ability to store explicit information to be referenced and manipulated in the future. For example, “if the user moves one vertex of a polygon, both adjacent sides will be moved. If a user moves a symbol, all lines attached to that symbol will automatically move and stay attached to it”. At first glance, Sutherland appears to be drawing on screen, but in reality, what he has done is define a set of relationships that form a specific intent, what is today referred to as parametric modeling.

Today, CAD programs have become ubiquitous with the architecture profession. While the use of computers has been prevalent in other industries, it was not until the 1990s that architectural practices begin using computers for tasks other than word processing and accounting. Early attempts, such as Columbia University’s Paperless Studio, to embrace these new tools were viewed as “novel distractions rather than serious propositions for the future of design culture”. Now fast forward twenty years and we are in an age in architecture where it becomes hard to imagine a time before the use of computers. New students entering the field are presented with these machines side by side drafting boards and triangles. As a result software such as AutoCAD, Rhino, and SketchUp have become ingrained in the repertoire of tools for architectural students and professionals alike.

This shift in some ways was “bound to happen” based on precedents set by the aerospace or automotive industries, but as Antoine Picon states in Digital Culture in Architecture, “technology is seldom the only explanation, especially in architecture where so much depends upon economic, social and cultural factors. The transformations that we are observing today, they are the result of a much longer and complex historical process than recent conversion of designers to digital tools.”

6 Ibid.
8 Ibid.
CONVENTIONAL VS PARAMETRIC MODELS:

In a conventional model, geometries are created and joined in a step-by-step manner. Starting with a blank screen, the layering of different parts ultimately makes up the final model (this applies to both digital drafting as well as digital modeling). What is important to realize with conventional modeling is the independent nature of these parts. Even though, they may appear to be visually connected to other elements on the screen if an item is moved the surrounding ones remain unaffected. This layering of geometries, results in the model being very difficult and time-consuming to change. For example, given the task of modeling a ladder type structure (fig 2.02). One traditional way of modeling would be to subdivide line A and line B by the desired number of rungs. Next, would involve manually drawing lines from the endpoints of the original subdivided lines. The workflow involves a series of steps that are dependent on the previous one.

From a design perspective, this can become very cumbersome. For example, due to other factors instead of the 26 rungs on the ladder, I now need 27. With the traditional workflow, there is no other option than deleting the already drawn rungs and starting from the beginning by re-dividing lines A and B and redoing the process of connecting all the endpoints. Due to the independent nature of the elements, what is realized is a direct relationship between the complexity of the model and the time and effort required to edit it. Now imagine the process of designing a building, whereas the ladder had but one variable, an entire building can contain an endless number.

Parametric modeling attempts to address this issue. By capitalizing on the inherent relationships that can be created between objects, parametric modeling aims to reduce the amount of time editing design elements. Rather than designing for a particular outcome, such as my ladder needs to have X amount of rungs, we can rethink what the intended outcome needs to be and evaluate the relationships that are inherent for that particular outcome. With the ladder example, we can realize how lines A and B are created by connecting by endpoints, A0 with A0 and B0 with B0 (fig 2.03). Secondly, the lines A and B will have the same number of subdivisions (which can be represented by the variable x). Furthermore, we know that to construct the rungs that points a1 and b1 will be connected by a straight line, points a2 and b2 will also be connected by a straight line, and so on. The result of this thinking leads to the creation of a parametric model that embeds design logics into the construction of the digital model. These logics, represented by mathematical rules, allow designers to change variables and visualize the resulting changes instantaneously, reducing the monotony of rework.
So why is the ability to make changes to a model beneficial for architecture? In 1976, Barry Boehm created a graph showing the increasing cost of change over time with respect to software engineering. The curve observes that as the product becomes more developed, it also becomes more difficult to change.10 In 2001, Boehm’s curve reappeared at a BIM conference when Patrick MacLeamy (of HOK) “showed that a designer has the most ability to impact a project’s cost and functional capabilities at the start of a project and that this ability decreases during a project while the cost of making design changes increases.”11 While MacLeamy was advocating the frontloading of architecture projects through IDP (integrated project delivery), he was also commenting on the decreasing influence a designer has on a project as it progresses. The introduction of parametric modeling was motivated by a desire to decrease the cost of change and in turn, give the designer the ability to make critical decisions later in the project’s lifespan.

This kind of design methodology requires a shift in thinking from a process of manipulating individual elements to that of pairing design intent with mathematical logic. The advantages of such allow for a designer to “embed [their] thinking into an active model – the creation of a design space in which every result satisfies the requirements of the design upfront, freeing one to explore solutions playfully”.12 Scott Marble calls this a “procedural” issue that “poses design itself as a design problem”.13 This is because expressing design intentions through the use of parameters requires a different way of thinking. Most designers are not accustomed to thinking about the logics that bind the design together. Robert Woodbury is also aware of this prerequisite: “Parametric design depends on defining the relationships and the willingness (and ability) of the designer to consider the relationship-definition phase as an integral part of the broader design process”.14

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11 Ibid.
PARAMETRIC LOUVERS:

For the design of the Museo Del Acero by Grimshaw Architects, parametric modeling was used for refining the design of the exterior louver cladding. A model was developed to allow designers to manipulate the louver rotation to allow for moments of transparency and opacity. “This model was then live-linked with the final construction output, a simple spreadsheet listing each louver’s alpha-numeric code and its corresponding rotation value. Within two days, the subcontractor was on site with a printed version of the spreadsheet, rotation the louvers into place”. Often referred to as a form of file-to-fabrication, this digital workflow allows for the designer to make critical changes up onto a project’s deadline at a nearly zero cost of change.

DESIGN TO FABRICATION:

Designed by ALA Architects, the Kilden Performing Arts Centre employs a parametric model for the design and production of the curved wooden surface that punctures the building’s southern facade. In this project, the surface is created by lofting together two curves. By setting up a parametric model, the architects were able to explore many design options by simply manipulating the original curves that create the lofted surface.

The consultant firm designtoproduction was brought onto the team to refine the geometry by the architect and respond to fabrication and assembly strategies. Designtoproduction rationalized the surface and integrated material properties and construction logics into the parametric model that allowed the project to be sent to a fabricator and assembled onsite in a scheduled manner. “The model [by designtoproduction] contained data for 14,309 glue-laminated girders and locally sourced oak cladding that were then output from this model and delivered to the timber fabricator for CNC fabrication”. By working directly with the fabricators and the architects, designtoproduction was able to straddle the line between design concept and buildable solution, simultaneously reducing complexity and increasing efficiency.

The benefits of using a parametric model with this project marry together the formal design intentions of the architect with the reality of construction and fabrication. “This workflow brings the engagement with materiality, detail and craft back into focus for the architects”.


18 Ibid
19 Ibid
Fig. 2.09 (above) - Kilden Performing Arts Center
Fig. 2.10 (right) - View from lobby
Fig. 2.11 (far right) - Roof detail
3. SHORTCOMINGS OF PARAMETRIC MODELING

3.1 A HYBRID DESIGNER
3.2 DESIGNING FLEXIBILITY
3.3 DESIGNING FOR UNKNOWNS
3.4 CHANGE BLINDNESS
3.5 OPEN SOURCE CODE
SHORTCOMINGS OF PARAMETRIC MODELING:

With any design project, the process is exploratory; it is about discovering something new. It is a process that is continuously undergoing change. Rarely, due to the scale of architecture, is an entire project pre-meditatively constructed within the mind of a designer and thus requires some mode of representation (drawings, physical and digital models, renderings, etc.). Parametric modeling is also about change. “In theory, a well thought out parametric [model] can increase the productivity, allowing for an increase in design iterations and the creation of variations in families of parts for fabrication”. With the ability to adjust parameters ad nauseam, the benefits supporting the construction of parametric models allow changes to happen to the geometry of a model with little effort and time by the designer.

However, there is a tradeoff. While parametric models offer the flexibility to allow for change, it is this very nature with can blindside particular models. Additionally, it becomes the responsibility of the designer to define the correct relationships that become integral to the success or failure of a parametric model in the first place. In the essay titled “Technical Notes from experiences and studies in using Parametric and BIM architectural software”, Rick Smith articulates five shortcomings from his experience in parametric modeling:

1. A Hybrid designer
2. Design flexibility
3. Designing for unknowns
4. Change blindness
5. Open source code

Smith has provided two interesting points with this critic. The first is his analogy between how an architect must begin to think more like a software engineer. This is also reinforced in “Elements of Parametric Design” in which Robert Woodbury’s states that in order to be successful at parametric design you must become “part designer, part computer scientist and part mathematician” Smith himself concludes this paper with a similar warning; “To implement parametric software in architectural design, a new breed of architects will need to be trained. [It] would need to be more rigorous discipline, not only in understanding three-dimensional geometry but also in the discipline of software programming and architecture”.

3. Ibid
The other important concept that Smith has presented is the idea of frontloading. Davis agrees and goes to add that “planning is a necessary component of parametric modelling because the logical rigidity of a model’s explicit functions requires that the designer anticipate, to some degree, the parameters of the model and the hierarchy of dependencies between functions” and concludes his argument with how “this upfront planning can be challenging, particularly in a process as notoriously hard to anticipate as the design process”.

Within my project, this idea of frontloading was explored in various 3D wall sections that I modeled. Early in the design process I realized the potential for some of my walls to be double curved but was not sure how that would affect the material I chose to clad the building with. While none of these particular walls translate to specific walls in the design, the intent was that through this study that results would set limits for how curved a wall could be.

Before even beginning to build the model I needed to plan out what would become my parameters, and how I could maximize the use of this one model. The result became a model built around a single surface. That way, as I chose to push or pull or bend the original surface the resultant cladding and space frame system would be automatically updated. The bricks that populate one side of the surface are also parametrically controlled so that I could adjust the width, length and height of each. Ultimately, this workflow allowed me to study any box shaped material by just adjusting a few parameters. This model ended up saving me a lot of time, especially in a process as tedious as modeling individual bricks.

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25 Ibid.
2. DESIGN FLEXIBILITY

"Once you think you have a working parametric model you may still find you haven’t programmed a parameter of the geometry in a way that is adjustable to a designer’s future request. A designer might say I want to move and twist this wall, but you did not foresee that move and there is no parameter to accommodate the change. It then unravels your program. Many times you will have to start all over again. Imagine trying to do this on a complex and fully integrated building."

Rick Smith’s second critic of parametric modeling reiterates the problematic situation of providing flexibility within a model to allow for future unknowns. The seemingly obvious solution to this critic would be to create parameters for every imaginable relationship in the model. However, aforementioned with the front-loading critic, in doing so would require more time and energy in building the model. Not to mention, the potential of a model being too complex for current computers to handle.

Through firsthand experience, I can attest to the frustration of working on a design without the proper computer hardware to back it up. As a result, the model needed to be split into many files, creating more frustration in the process and ultimately increasing the amount of energy required to make small changes. In the near future assuming computers will have the processing power to handle even the most complex models, there is no guarantee that the investment of spending extra time over-controlling a model will ever pay off.

The real challenge lays in being able to balance over-controlling and under-controlling the parameters in a model. Ideally, a designer should look for the most concise set of parameters that offer the greatest range of flexibility. Often it can be misleading to look at other designers’ “scripts” and be impressed by the complexity of them. When in reality, it is the simplest of such scripts that are a truer measure of adeptness.

3. DESIGNING FOR UNKNOWNS

"After all the time and effort of programming the geometry to where you think you have it right, you may find you still have to start all over again because the initial design concept has completely changed."

Here, Smith is referring to the fact that over the course of any project there will always be elements out of the control of the designer. A client may change their mind about the program of a project, or the budget will be cut, or material costs will change. These major changes have the potential to disrupt the parametric model to the point where it is no longer usable. While these types of changes can also drastically affect a design using more traditional workflows, they never the less can have a profound impact on the way a parametric model functions. As a result, designers attempting to use parametric models must be conscious of the possibility of significant changes in order to safeguard the amount of work put into a model verse the future work of changing a model.

A solution to this, what Robert Woodbury refers to as “throw away code”, or in my mind, the ability to see a parametric model in the same way one would view a sketch. Just as Adobe Photoshop and Adobe Illustrator are both tools for image creation and manipulation, and because there are certain times when you would use one over the other, there are times when you would use a parametric model and others when you wouldn’t. Woodbury claims that design by nature is ever-changing and that “from project to project, day to day or even hour to hour, [architects] tend to rebuild rather than reuse”. He goes further to explain how parametric modeling opens new windows in form finding and its real benefits lay in creating “endless opportunities to explore for forms that are not practically reachable otherwise”.

Smith agrees due to the likelihood of parametric models becoming unusable and states “parametrically controlled digital modeling works well for quick iterations of a project allowing a designer to step through many ‘what if’ concepts much quicker.”

Throughout my research, one of the most misleading ideas surrounding parametric models is the misconception to think that parametric modeling is a panacea that will solve everything. This is entirely false. The model is only as good as the information or data put into it. When using parametric models you have to evaluate quickly how much time it is going to take to create the model and what you will get out of it (the number and quality of the iterations). This is weighted against how long the same tasks would take to do manually and if it is quicker to do it manually the answer is obvious.

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4. CHANGE BLINDNESS

"Once your have your program working if anyone changes a parameter it could affect the geometry somewhere in the design that you didn’t want to be changed. This occurs often and the change may not be detected until much later in the design phase, or even worse, in the more expensive construction phase"  

Ironically, the relationships that are created in a parametric model to reduce the time spent editing are again the very thing that becomes its hindrance. For example, we can take a look at a how a situation would be handled in a non-parametric vs. parametric model. For whatever reason, a wall needs to be moved X" in one direction, in a non-parametric model that wall would need to be updated in any relevant drawings, sections or interior elevations. It is a process that could become very time-consuming and if not updated correctly on all the drawings cause inconsistencies in the construction process.

On the other hand, granted there is a parameter to move that wall in the first place, or given it is a BIM software such as Revit, that wall would be automatically updated in every necessary drawing but in doing so causes the wall to intersect with a mechanical shaft. Often the designer will be unconscious of this problem because it was created in a “behind the scene” nature. This is a phenomenon Daniel Davis calls change blindness and goes on to add that “if a designer is unable to identify what has changed between two model variations, then they may struggle to make an informed evaluation of design changes”.


5. OPEN SOURCE CODE

“This also points to the fact that any operator using the model needs intimate knowledge of the parametric program that is written for that specific design. This logic knowledge is not easily transferred with the 3D model. In a sense the original programmer of the model then becomes the owner of the model. Many times if the program is too complex and original programmer is the only one who can work with it” 33

Stemming from the previous critic, Smith is articulating how without a proper understanding of the relationships within the parametric model they become difficult to reuse and share. While this may be true to a certain degree, it may not be as critical as Smith has stated. A growing literacy of parametric code or scripts is seen on online forums and other web resources. Grasshopper3d.com is popular open source blog that encourages users to share and troubleshoot each other’s scripts. Many universities alike have developed similar digital resource libraries for students to view and contribute. Ming3d.com, curated by Ming Tang, a professor at the University of Cincinnati, is a website with free online courses for all levels of students. The course library is organized by searchable keywords and tags, offers more than 100 hours of video tutorials and has been visited 379,000 times since 2011. 34

A comment which Smith is perhaps alluding to is the fact that the software which architects use is authored by computer scientists and not designers. “Architects have been hijacked! The tools they are working with are written by programmers whose training, by and large, comes from a very scientific, engineering-biased mindset. These tools provide the language that architects have to use, and as architects start becoming more proficient with the tools, they start adapting to the engineers’ language”. 35 David Benjamin, a co-founder of The Living, observes just this: “of course, many young architects are already fluent in developing digital workflows and writing custom scripts within software applications. But the algorithms in these custom scripts may have a limited influence on the design results in comparison to the algorithms in the core software application”. 36

36 Ibid.
CONCLUSION

4.1 FINAL THOUGHTS
At its simplest, parametric modeling is about designing the constraints around which an object is created rather than designing the object itself. These constraints are expressed through inputs, which are then filtered through equations to provide outputs. This way of thinking differs from the tradition mode in that it requires the designer to think of a solution in terms of a system. The goal of which is the creation of a model that provides the flexibility to change and fulfills the digital paradigm of the speed of representation. It can appear at first that design has been reduced to a series of mathematical equations but as Wassim Jabi concludes in his book Parametric Design for Architecture that “the real challenge in parametric design is not how clever the algorithm is, or how complicated the output is, but in the selection of the initial input parameters” (Jabi 2013). “For architects, parametric models purportedly improve the designer’s ability to make changes, thereby improving their capacity to design. In theory a designer can modify a model’s parameters and see the design change almost instantly. As such, parametric models have come to be understood in terms of their outputs; a method for producing tools, or making parametricism, or creating design representations that change in relation to parameters. This focus on what parametric models do suggests a separation between creating and doing, a separation that underplays the significance of creating and maintaining a parametric model” (Davis 2013)

Currently, parametric modeling is a game of balance between the quantitative and qualitative elements of any design project. The most basic quantitative elements are undeniably popular with students, but a more rigorous approach is necessary to take parametric modeling beyond a novel tool for making complex forms. “In order to truly connect parametric design to everyday activities of designers, they need to understand and represent the same issues the designers are working with: geometry and topology, but also architectural components, materials, the environment and people” (Jabi 2013).

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