The type chair: formal and economic optimization in full-scale 3d printing

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ABSTRACT: This paper discusses the implications of full-scale 3d printing when confronted with normative economic constraints in relation to desired formal outcomes. To explore this, we designed the *Type Chair*, which includes in its design, a cost and form optimization algorithm that ties the specifics of formal outcomes directly to cost. We describe the design of the chair and its accompanying algorithm, as well as the results we've gathered by employing this process. There is cutting edge, well documented work being done in the domain of 3d printing which suggests a potential paradigm shift for future architects and their approach toward design and construction. These processes embrace the notion that an architect's role is evolving away from the development of singular fixed objects and into the conceptualization of objects whose form changes based on the inputs and desires of a lay audience. The novelty of the approach in this project is the interrogation of how 3d printing processes may affect formal iteration and control in relation to normative market processes and forces. There is an ongoing revolution in the way objects are being conceived and made, and perhaps more importantly, an evolution in the expectations of a lay public whose daily engagement is now with devices and objects which have, as a primary ethos, the character of individual responsiveness. These discussions are important as we confront the potentials and limitations of full-scale 3d printing as a construction type, and how these emerging processes will affect architects and their changing role in the years to come.

KEYWORDS: Computation, digital design, post-digital, 3d Printing

INTRODUCTION

Although 3d printing has existed for several decades, its normative use as a full-scale construction method in architecture is still in its relative infancy. This paper discusses the implications of full-scale 3d printing when confronted with normative economic constraints in relation to desired formal outcomes. To explore this, we designed the *Type Chair*, whose form would be prohibitively difficult to build with any process other than 3d printing. Knowing that the normative market cost of full-scale 3d printing is often prohibitively expensive, we developed an algorithm using Rhino/Grasshopper/Python that iterates the chair within given economic constraints. In this paper we describe the *Type Chair's* design considerations along with the development of an optimization algorithm used to iterate the chair in relation to projected cost. There is cutting edge, well documented work being done in this domain which suggests a potential paradigm shift for future architects and their approach toward design and construction. These processes embrace the notion that an architect's role is evolving, away from the development of singular fixed objects, and into the conceptualization of objects whose form changes based on the inputs and desires of a lay audience. The novelty of the approach in this project is the interrogation of how 3d printing processes may affect formal iteration and control in relation to normative market processes and forces. There will no doubt already a revolution in the way objects are being conceived and made, and perhaps more importantly, an evolution in the expectations of a lay public whose daily engagement is now with devices and objects which have, as a primary ethos, the character of individual responsiveness; difference, not sameness, will typify the years ahead for spatial production. These discussions are important as we confront the potentials and limitations of full-scale 3d printing as a construction type, and how these emerging processes will affect architects and their changing role in the years to come.

We have structured the paper in five short sections. Section one is an abbreviated discussion about 3d printing processes and their cultural implications. Section two discusses the design and iteration of the *Type Chair* and many of the considerations and implications therein. Section three briefly discusses how the discourse in architecture begins to change based on the process of 3d printing. Section four addresses the considerations of normative economic constraints that arise when considering 3d printing as a construction method. The general spirit of this discussion centers on the disallowance of our attempt at affordability to weaken what we consider the formal and spatial strengths of the project. And finally, the last section discusses the iterative outcomes and what we've learned from these processes.

1.0 MACHINES OF DIFFERENCE

The general discourse that arises from the promises of new forms of making such as 3d printing are worth briefly discussing in order to provide some context for the work herein. As has been well documented, processes of digital making, such as 3d printing, help change the cultural expectations of objects. As a culture, we have relatively quickly emerged from a world of standardized production, are currently living in a world of configured production, and are in a rapidly evolving and expanding realm of parametrized production. That's not to say that standardized production types don't still exist, it's simply to offer that processes of standardization are beginning to give way to newer processes made possible by digital software and production. The nature of these emerging processes alters the discourse about objects themselves, but also alters societal expectations, which will have a direct impact on the discipline of architecture and how we make buildings in the future.[i]

In *The Alphabet and the Algorithm*, Mario Carpo outlines how the cultural expectation and recognition of objects emerges from the way the object is produced. According to his argument, the pre-industrial process of constructing numerous hand-crafted copies of objects left each one slightly visually different from the next. This meant that visual 'similarity', rather than 'sameness', was a primary way that people intuitively understood objects. The industrial age transformed this paradigm, allowing us to build as many identical copies as we desired. This evolved our visual expectations from that of 'similarity' to that of 'sameness'. Contemporary digital tools such as CNC machines and 3d printers, in conjunction with parametric software, begin to force another paradigm shift characterized by visual difference from one object to the next. The parametric software is virtually a machine of difference within given sets of parameters, and the CNC machines and 3d printers are not particularly punitive when the thing printed or cut changes from one object to the next. If the promise of parameterized production is that objects become individualized to the people who desire them, one can imagine the implications of such a change in design thinking, production methods, and the economics of the made object.[ii]

Carpo's argument establishes a theoretical benchmark from which we can begin a discussion of, in the case of this paper, the effects and implications of full-scale 3d printing. For instance, how is design transformed when full-scale 3d printing meets normative economic constraints? How do we discuss the litany of formal transformations within the objects themselves; does this revive typological questions and instantiate topological ones? Does the fact or promise of difference achieved through these processes transform the architect's role? We are using the *Type Chair* to explore many of these questions and in this paper are focusing mainly on the maintenance of a formal language through digital iteration specifically related to economic considerations.[iii]

1.1 Design logic, formal language, resonance

The Type Chair is specifically designed as a provocation to the questions posed above. Within this project there were a few key questions that acted as design generators. First, how do we create objects that would be difficult if not impossible to produce with methods other than 3D printing? Second, how can we evaluate economic constraints and test the implications of aggressively moving in the direction of general affordability in this regard? Finally, what are the formal implications of a process that creates a litany of unique examples? (Figure 1)

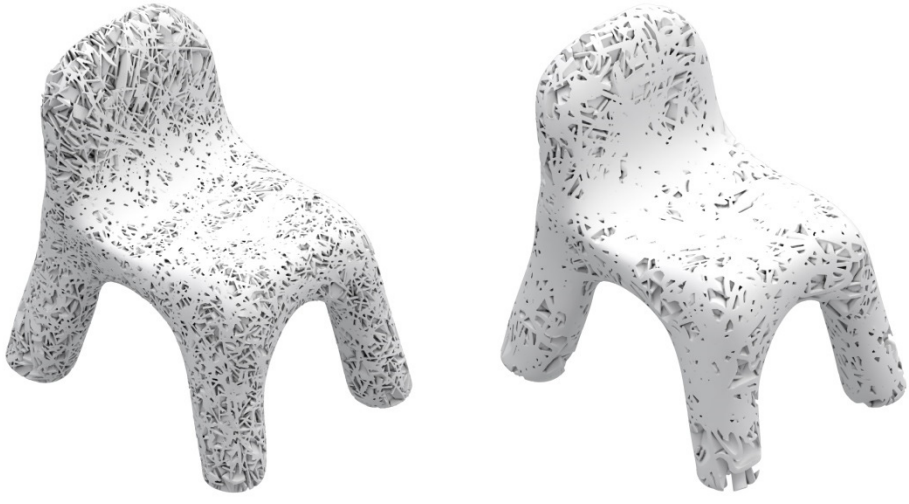
Different Letters Different Sizes *Different Letters Same Sizes* *Same Letters Different Sizes* *Same Letters Same Sizes*

Figure 1: Type Chair – Four Variants. Source: (Frank Jacobus, Jeff Quantz 2019)

Volumetric complexity was a primary ambition in the *Type Chair*. This complexity creates an object which would be extraordinarily difficult to build with other tools and methods. It also directly challenges the notions of object to object uniqueness in relation to comfort, structure, and affordability. To produce something with a simple surface and form would have meant creating an object that could have easily been produced another way. This avoids the challenges that are likely to emerge when dealing with digital tools that present an inherent promise of formal complexity and difference. We've built several projects invested in ideas of formal resonance - that is, recognizable forms distorted, fragmented, or otherwise altered and placed in a new context – and so were intrigued by how that way of thinking could be employed in this process.

The alphabet began to make sense as a DNA for the chair for several reasons. First, individual letters are forms in the world that we interact with every day; so much in fact that we take them for granted as forms in and of themselves. In the design disciplines these letters, as fonts, are part of our enculturation. We tend to gravitate toward certain fonts and away from others, we make judgements about our colleagues by the fonts they use, and as architects we look strangely at people who have used a serif font when a perfectly good sans serif font was available. However, it's likely that most people in the western world interact with letters and fonts in a primarily subconscious way. We could analogize the meaning of fonts to the meaning of the built environment for lay people. Most people pass by and through buildings without a second thought about their design or meaning; and thus, it is with the alphabet itself – this technology that has so greatly affected our everyday lives, exists beside us, compels us, and propels us, yet is virtually absent from our conscious minds. By using letters in varying fonts as the *Type Chair's* DNA, we present the most familiar yet forgettable form into an unfamiliar context. This means that the edges, curves, shapes, of which we are so intuitively familiar, when scaled and intersected, become something new that carries with it meaning from its previous existence.

Next, the letters, especially in a nested configuration, offered us the important formal complexities described above that would be difficult to build without the use of a 3d printer. We knew that the Boolean Union of letter forms would create new hybrid shapes of solids and voids. These unexpected shapes become like a portmanteau that holds within it some slight possibility of a phonetic marriage that creates new meanings; in this case, non-literal meanings that offer formal resonance and familiarity. There's something compelling in the notion that we can recognize the movement of certain lines in the chair that are familiar yet not immediately be able to read the chair as a literal text. (Figure 2)



Same Letter Same Size - Helvetica *Different Letter Different Size – Comic Sans*

Figure 2: Formal Variants. Source: (Frank Jacobus, Jeff Quantz 2019)

The use of letters also acts as a play on the emergence of abstraction and automatic processes in art. As we discussed above, 3d printing and other emerging digital processes promise formal variation through parametric means. The alphabet itself is relatable to this way of making meaning; the rearrangement of set components (letters) into a vast array of meaningful configurations. The chair is metaphorical in this regard, as it embraces the world of abstraction, coding, and classification that the alphabet itself gives rise to.[iv] It perhaps becomes a playful way of giving the Alphabet Effect, proposed by Robert K. Logan and eventually the Toronto School, a visible and perhaps ironically literal form.[v,vi,vii] But the *Type Chair*, along with all emerging processes of design and construction, also lives in a contemporary digital environment wherein all causality is lost upon lay users while their expectations and wishes for multifarious affects are granted. So, if as McLuhan suggests, the alphabet itself gave rise to mechanization, perhaps the use of letters in the *Type Chair* makes sense as a way of seeing 3d Printing as an heir to these processes.[viii]

Due to the complexity of the use of nested letters, and a desire to employ some sort of dependent variable, we designed the chair with a simple profile that became counterpoint to the complexity of the nest. We also needed something with relative thickness that would be able to visually support a tenuous nest of letters. A thin form in conjunction with the nested letters would have likely yielded structural issues at the joints, especially given the materials that can be effectively 3d printed at this time in normative consumer markets. A thin chair would have also risked a visual failure of sorts as there is a mystery that emerges from that which gets lost in shadows caused by the deep voids between the letters. Finally, we rounded the edges of the chair for comfort but also to help visually distort some of the letter shapes. (Figure 3)

2.0 ECONOMICS OF THE EVERYDAY

There is currently incredible work being done in the realm of full-scale 3d printing. Ronald Rael and Virginia San Fratello, in their book *Printing Architecture*, provide recipes for printing with numerous materials and reveal some of the sensuous formal resultants.[ix] Neri Oxman and her colleagues at the MIT Media Lab have been developing 3d printing strategies with new materials and techniques that are transforming the way objects are made.[x] Similarly, figures such as Achim Menges are invested in questions about new materiality in relation to emerging fabrication types.[xi] The project described in this paper is less interested in materiality at this stage, and more invested in questions of form, economics, and user controls that arise as

these new methods of making evolve. This cost/form/client relationship has a lot of fascinating implications for designers of 3d printed objects. First, it begins to tackle issues of formal uniqueness, as discussed in the first part of the paper, without assuming that there is no relationship between form and cost – and without assuming that users aren't going to expect to be an integral part of design processes in the future.

3d printing costs are almost always directly related to printing time, which itself is directly related to the amount of material used in the chair and support material. Reducing construction cost while maintaining design quality became a major concern when developing the optimizing algorithm. What we found through the iteration of early *Type Chair* studies is that forms and edges buried within the chair's interior were radically increasing the amount of material used for the final printed object. We discussed several ideas to rectify this, some of which were suggested by the 3d printing company itself. First, we could inset a second surface an inch or two off the chair's outer surface, creating a bubble within the chair's interior which would eliminate the extra lines within the body of the chair. This unfortunately would result in a form whose thin shell could be read immediately, eliminating much of the line and shadow play that makes the *Type Chair* compelling. We believed this was one of the great aesthetic attributes of the chair – the ability to see through portions of its complex surface, catching glimpses of fractured surfaces beyond.

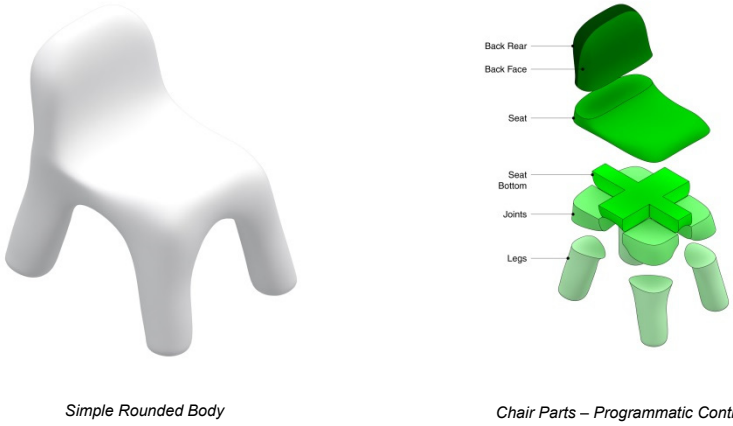
Another strategy of course would be to convert the chair into a patterned surface entirely. This would be the least expensive option but was untenable due to an exaggeration of the issues mentioned above. We now understood that our task was to reduce line complexity where it would not be seen anyway; primarily in areas where fragments of letters existed within other letter extrusions. But the initial economic exercises themselves created numerous questions for us about ways we could generally test the economics of various formal options to find the underlying relationships between form and expense. So, we decided to iterate the chair design in relation to the following fundamental question: how do the economic implications of 3d printing become formal or spatial drivers in a project, without degrading the desired formal qualities? In other words, we knew that we could value engineer the form to lower the chair's overall cost but determined that this was not a satisfactory way to approach design; especially with the formal promises that 3d printing suggests.

Two major area of consideration emerged from these foundational questions. First, how does one optimize process and form in order to achieve a desired aesthetic while simultaneously driving down cost? Next, but no less important, how might this optimization process evolve the aesthetic, and what implications does this have for architects in the years to come. Because the DNA of the chair consisted of font itself, many questions began to emerge with respect to the alternation of specific font types, sizes, and the inclusion/exclusion of specific letters as formal drivers that would each have cost implications. For instance, would certain fonts inherently cost more than others? Would serif fonts inherently cost more or less than sans serif fonts? Would the scale of the letters themselves affect the overall cost? These and many other questions became the central to the project.

3.0 OPTIMIZATION AND ITS CONTENTS

Once we understood the general implications outlined above, we began digital optimization efforts in Rhino/Grasshopper/Python that centered on issues of cost, structure, comfort, and form. While these four issues are linked in an inextricable way, the general value of each changes slightly dependent upon which part of the chair we're considering. To accommodate this and create a more rigorous optimization tool, we divided the chair into six parts, each having their own programmatic requirements. The six divisions are *Legs*, *Joints*, *Seat Bottom*, *Seat Top*, *Chair Back Face*, and *Chair Back Rear*. This allows our algorithm to specifically define element densities (and potentially sizes) based on specific needs without having to manually perform these operations. At potentially tenuous areas, such as the *Joints*, where the legs meet the *Seat Bottom*, more structural capacity is required and therefore more assurance of letter density was needed. At the *Seat Top* and *Chair Back Front* more density

was also required for comfort but potentially a different density level than at the *Joints*; the allowance for this density creates a smoother, less striated surface. The *Legs*, *Seat Bottom*, and *Chair Back Rear* don't require density for comfort or structure so could each employ different levels of sparsity if desired to save in overall material cost. (Figure 3)



Simple Rounded Body *Chair Parts – Programmatic Control*

Figure 3: Simple Shape Broken into Parts. Source: (Frank Jacobus, Jeff Quantz 2019)

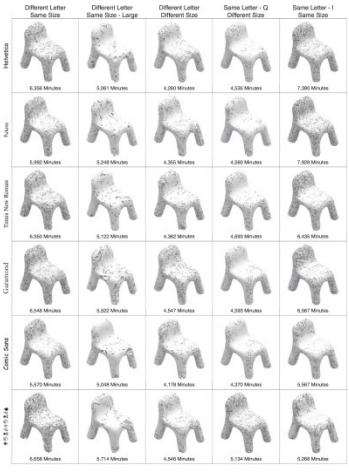
Form, or the chair's visual performance, was of vital importance, and the optimization algorithm allowed for varying level of controls in this regard. For instance, at the *Chair Back Rear*, the *Seat Bottom*, and the *Legs* there is a greater allowance for formal liberty than there is for the other parts chair. So, these areas have a greater capacity to deliver desired form, but also have a slightly increased capacity to affect overall costs. In other words, the user or designer can manipulate these areas more, but their manipulation has a direct cost result that is controllable.

For each test, the algorithm randomly chose a letter from the font family, converted it into a surface, rotated the surface, and then scaled it appropriately to the specific test. The algorithm then populated each chair part (*Legs*, *Joints*, etc.) with a point and assigned the manipulated surface to that point. Finally, the algorithm extruded the letter, split it using the outer shell of the chair, removed any geometry that fell outside the shell, and Boolean Unioned the remainder to the existing aggregation. The algorithm checked the volume of the resulting object and continued to run until the desired criteria of structure and aesthetics were met. Typically, the larger the letter, the fewer times the algorithm ran.

Our optimization algorithm embraces design rules set by economic constraints yet is equipped for a changing cultural environment that demands more lay person control within these constraints. These are the type of discussions that are likely to emerge as we evolve into designed environments wherein objects are not single repeatable entities, but rather are unique one-offs that emerge from a set of predefined rules unknown to the everyday consumer but whose forms are affected by them.

4.0 ITERATIVE ANSWERS

The original *Type Chair* was designed and sent in for pricing without any optimization algorithms in place. In order to iterate the design of the chair we would have to re-nest extruded letter forms, changing their sizes manually, and then re-boolean each outer chair profile out of the constructed nest. This process belied the promise of 3d printed objects, which fundamentally has to do with quickly delivered uniqueness from one object to the next. To truly embrace the processes we were dealing with, and to assume their eventuality within normative market economies, we created an algorithm that allowed for endless iterations that could easily be visually compared, priced, and reiterated based on transparent criteria. In Figure 4 we show the various iterations we've built to this point and how much print time is required for each.



Chair Taxonomy – Cost Relationships

Least Expensive Chair to Print
Different Letters Different Size – Comic Sans

Figure 4: Taxonomy of Cost and Form. Source: (Frank Jacobus, Jeff Quantz 2019)

Several patterns emerged from the compiled printing time data. First, the larger the letter, the faster the print time for the chair, thereby making it the least expensive option. We tested the same letters for each type face with 1 inch and 6-inch-tall letters. The 1-inch letters took 43% longer to print than the 6" letters. In addition, and a bit ironically perhaps, the serif fonts printed 2% faster than the sans serif fonts. Comic Sans printed the fastest by 10%, which makes sense due to its cartoon quality. An unexpected result occurred while testing the letter 'I' across all fonts. The sans serif fonts of Helvetica and Futura typically printed faster due to the decreased surface area of the letters inherent in the stark font family. Focusing only on the letter 'I', the decreased surface area of the letter created an increased surface area in the chair, leading to a print time 45% greater than WingDings, the fastest in that category. We added WingDings as an anomaly font and found it useful both as a cost comparison mechanism but also as a formal aberration. We now have the algorithm workable enough to allow quick iteration and relatively immediate feedback regarding cost. Strategies like these will allow designers to build in their own value engineering mechanisms in ways that ensure that the spirit of the designed object is not lost.

CONCLUSION

Development of the *Type Chair*, and the algorithm used to produce its unique variants, was a foundational full-scale 3d printing experiment situated at the intersection of economics and form. This project considered how underlying, often hidden programmatic considerations for individual objects, must be addressed in relation to economic effects as we move toward parametrized models of object production. These optimization experiments should translate well to any material that one chooses to print with in the future due to the general linear relationship between printing time and cost.

3d printers should be thought of as machines of difference. The new construction techniques promised by these tools will begin to engender a world of objects that are unique one to the next. Though the discourse of 3d printing often centers on the democratization of design by lay users, the reality is that these consumers don't want to assume the responsibility for the conception of these objects, nor do they want to bear the burden of the time it takes to invent, draw, and make them. What it does imply however, is that they will expect uniqueness in their object world; a world in which methods of customization will become commonplace, and the inability to customize will be unacceptable. Designers are vital in this parameterized world and

it will be up to us to determine not only the individual object aesthetic as in the past, but more importantly, the object language and rules. This is the path to the promised future of the appearance or perception of infinite choice and variety for consumers. Designers have an enormously important role to play in this emerging world. As this new way of making evolves, architects will not only have to design objects, but we will also have to understand their DNA and what that means for their potential variants. To design in a world of parameterized objects means to go beyond fixed, immobile form - to design the rules that affect real-time object transformation.

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