Parametric Architecture

From Technique to Aesthetic

By: Ben Connolly, MArch

Introduction

Architectural history, theory and criticism lives as an on-going documentation of the trends in the profession, where they have come from and the direction they appear to be taking. With its intricate cultural link as indicative of place and time, fluctuating trends put architectural design into a continuous tension with its societal context. Architecture as a design discipline has been uniquely positioned to react culturally because of its fundamental function as shelter, and so has been influenced heavily by this evolution in tandem with the greater scope of interdisciplinary design disciplines. While by no means universally agreed upon, there tend to be four general transitions in architectural theory as they affect practicing architects currently working today. In the particular context of this writing, these groups can generally be divided into: I) Before Modernism, II) Modernism, III) Contemporary, and IV) Beyond Contemporary. Historian William J.R. Curtis explains that the initial central Modernist shift was formulated in the late 19th and early 20th centuries as a rejection of the litany of various stylistic revival devices that preceded it. Building on this, theorist Kenneth Frampton of Columbia University breaks Curtis's transition into two main categories: "…the utopianism of the avant garde… and that anti-Classical, anti-rational and anti-utilitarian attitude."[1] This Modernist shift rejected previous notions of what typologies should be, and instead reconsidered them from a functionalist, sometimes expressive point of view. To this point, Curtis opines that Modern architecture "…should be based directly on new means of construction and should be disciplined by the exigencies of function; its forms should be purged of the paraphernalia of historical reminiscence…"[2] to reflect the ongoing critical shift of the time. This train of thought set the basis for the peak of the Modernist movement from the 1950's to the 1970's throughout many creative disciplines, and persists as a fundamental idea in the contemporary works of the 21st century.

Looking at the discipline in the contemporary era, it is apparent that another shift is underway, as digital technology re-invents the way offices work. Computers, in particular, are increasingly shaping the discipline, and as Asperl, Hofer, Kilian & Pottman note "…the variety of shapes that [can] be treated by traditional geometric methods has been rather limited, modern computing technologies have led to a real geometry revolution."[3] In moving forward, it has become clear that the widespread onset of the computer has diversified the range of work being completed, as well as exponentially increased the complexity and efficiency of those projects. Human limitations to geometry are rapidly disappearing, because "…the computer 'liberated' architecture from the tyranny of the right angle, and enabled the design and production of non-standard buildings, based on irregular geometry."[4] This has led to a newfound diversity and complexity in architecture that allowed for new ways of thinking in terms of how designers work, establishing an ongoing evolution where "…the tools at our disposal are becoming seemingly unlimited."[5] One of the most notable of these is the emergent idea of parametric architecture, quite literally the use of user-established parameters to define a solution space to an architectural problem. This process is championed by a variety of leading contemporary architects and designers, with Patrik Schumacher of Zaha Hadid Architects in London leading the movement. He insists that the contemporary architectural profession must move forward, away from its Modernist origins and torward a single, coherent goal; his belief is that Parametricism can be the uniting force for this. Over the last two decades, Parametricism has grown from a little-known design process into one of the most visible styles of architecture. As Tedeschi notes, "… the influence of parametric technology is becoming increasingly apparent on contemporary architectural language."[6] This is a relatively new way of perceiving parametric design. Initially, parametrics fell into the category of technique as a result of its roots in applied systems or scientific approaches to design. This change prompts an important question: How and why has parametric design shifted from its origins as a technique to its current manifestation as a primarily visual aesthetic? To answer this it is first necessary to establish a framework that explains parametric design, its historical influences, its conception as a building process, and finally its recent tendencies into the realm of aesthetics and symbolism.

What is Parametric Design?

Despite being a common thread in the contemporary critical discourse of architecture, it seems that the definition of "parametric design" is as broad as the term's application. Numerous publications each provide an interpretation of what it means – and not surprisingly, many of the world's leading architects are quick to offer their own definitions of the term based on their own work, both in professional practice and academia. Since their definitions are directly influenced by their practice (and therefore possess monetary gain for the success of that personal definition), it is important to have academic interpretations of the term as well, particularly those who have a disinterested point of view in the debate.

Simon Fraser University professor Robert Woodbury leads an academic research group focused on parametric design and emergent digital technologies. He defines parametrics as "…an attitude of mind that seeks to express and explore relationships… Instead of building a single solution, designers explore an entire parametrically described solution space."[7] The process Woodbury describes could be considered as designing not only in the second- and third-dimensions, but in the fourth dimension as well: "The idea of capturing *design history [digitally]* and returning it in an editable form… that design history can be extrapolated to produce design futures."[8] Woodbury attempts to take a step backwards and survey the concept without preconceived notions, much in the same way Modernists did with revivalist styles before him. Thinking in this manner allows the designer to realize broader connections and trends they would otherwise miss at a smaller building scale. Looking at a design problem *parametrically rather than architecturally* frees one of the limits of thinking in a detrimentally formalist or functionalist manner: "Parametric concept disregards the formal result that, at the initial stage, is often indefinite in a designer's mind. On the contrary, the concept is supported and strengthened by the metaphor."[9]

Roly Hudson offers the following definition "…parametric design is understood as a process where a description of a problem is created using variables."[10] As the designer is looking at the variable points of a design problem rather than the singular direct solution, the nature of design starts to fundamentally shift from the static notions of singular additive and subtractive forms. Similar to Hudson, Woodbury explains that in conventional modeling designers would cut, copy, and/or paste individual pieces together or apart to build up an idea of their form; in reality this is not much different from the oldest methods of physical modeling, albeit faster. "Copy, cut and paste works in conventional design precisely because of part independence…"[11] of the various shapes the designer is including in the formal whole; however this method can be limiting based on its rigidity and lack of forgiveness in changing the model at the latest stages of design. Parametrics, Woodbury notes, addresses this problem directly: "Rather than the designer creating the design solution (by direct manipulation) the idea is that the designers establishes the relationships by which parts connect."[12] These become parametric functions with variable inputs and outputs, and in this way start to interact as a network system rather than a series of parts. Complexity increases with this method; however, it need not be detrimental. On the contrary, it can lend a purity of design intention to the parametric process, where "…the phenomenon of architecture can be most adequately grasped if it is analyzed as an autonomous network (autopoietic system)"[13] rather than arbitrarily influenced by external forces to the concept, as shown in the Kartal-Pendik Masterplan of 2006 (Figure 1).

As arguably the biggest proponent of parametricism, Schumacher has made it clear how he defines the term: "Parametricism implies that all elements of architecture and object design have become parametrically malleable, which in turn implies their capacity for adaptive affiliation and a general intensification of relations."[14] Schumacher argues that as a network, parametric design is flexible and can determine the overall constant in the relationship between any group of things and then distill it down to a single, communicable essence. Schumacher's hope is that this collective strategy can create a coherent, single direction for the profession due to the wide ranging applicability of parametricism and the number of design issues it can address.

Unlike Woodbury, Hudson, and Schumacher, Greg Lynn takes a very different approach when defining the terminology and methodology of parametric design. In Lynn's opinion, parametricism is a simplified imitation that misses the limitless opportunities his own animation-informed methodology instills. He criticizes them as "…design strategies that generate possible solutions in the hope of [a] happy accident… the resulting work can only be described as ugly [and] amateurish."[15] At its core, Lynn's process still uses parameters, just like Schumacher, and is therefore parametric; however, where others use parameters to install a set of limitations as a solution space to be cycled through incrementally, Lynn uses simultaneous animations to formulate a limitless range of possibilities as suitable to the problem at hand (Figure 2).

The vastness of the subject, combined with the number of individuals working in the field, makes it difficult to definitively define the term 'parametric', but perhaps that is appropriate for the adaptive nature of the work. However, common themes point to a disposition towards broader contexts, the definition of networks and their interaction, flexibility to explore a variety of design choices throughout the process, and a focus on the connection between objects rather than the objects themselves. The examples presented serve to illustrate the fact that each of these individuals have established academic or professional practices drawing on different themes of parametrics as they relate to their work. Each presents unique applications for achieving different goals, and all are relevant methods – some more so than others.

Parametric Origins

Historical references of parametric architecture tend to be difficult to find, largely because of the ambiguity of the term 'parametric' in various historical situations. The term originated in the field of pure mathematics where reference to it are found more frequently than in architectural contexts. Disregarding instances of the term being used, but not put into practice, the first occurrence of parametric design within an architectural context can be found in Luigi Moretti's work, especially in his idealized football stadium (Figure 3), and later the Watergate complex.[16] He wrote that these were "…the study of architecture systems with the goal of 'defining the relationships between the dimensions dependent upon the various parameters.'"[17]

While there is a general agreement that 'parametric' design goes hand in hand with digital applications, this is not necessarily the case. One of the first truly three-dimensional parametric applications was Antonio Gaudi's use of catenary curves in his physical modeling for the Sagrada Familia (Figure 4) and Colonia Guell. The basis behind catenary curves states that allowing a chain to fall when holding it from two hands gives the curvature of ideal vaults, based on the fact that "…the strings would always settle into a shape that, when inverted, would stand in pure compression."[18] Knowing that gravity will always pull the chain down into the inverse of pure compression, Gaudi was able to explore different shapes and series of vaults simply by moving the ends of the chains and avoiding recalculating the form. Therefore, "…the hanging chain model has all the components of a parametric equation… the key innovation of Gaudi's hanging chain model is that it automatically computes the parametric outcomes."[19] Davis also notes that this was later employed by Frei Otto for his "…minimal paths found through wool dipped in liquid;"[20] currently the parametric software Grasshopper for Rhino uses a command called "Shortest Distance," which employs the same functional principle across complex surfaces.

The first uses of parametrics in real-world applications that begin to offer evidence of directly influencing future digital trends comes from Ivan Sutherland's doctoral research that eventually led to the invention of

SketchPad in 1963, the first human-computer interaction in computer aided design (CAD) software. This had a profound affect years later in the emergence of a variety of software, most notably AutoCAD, Bentley, Maya, Revit and Rhino/Grasshopper, all of which employ some version of parametric programming, either directly or indirectly, and emulate the human-computer interface pioneered by Sutherland's SketchPad.

The Process of Rationalization

One of the foremost issues confronting parametric design in the practical (ie. built) world is the process of translating the digital model, which is inherently created to produce an optimal geometry according to a pre-defined set of constraints, into a tangible and physically constructible reality. In the new digital age of architecture, "…computer fabrication has opened a realm for architects to perceptually heighten and make visible the nature of [digitally fabricated building components]."[21] In terms of defining this transition, Hudson outlines two basic categories that cover the full spectrum of methods: "Rationalisation refers to the application of known geometric principles and construction techniques in order to realize a project. Post-rational is where geometry and construction constraints are considered after a conceptual design phase. When geometric method is rational from early design stages it is referred to as pre-rational."[22] What Hudson describes are two distinct systems of operation. Firstly, a system where the architects are working primarily with a specific, singular geometry chosen for its inherent qualities to solve the design problem at hand. Alternately, a system where the architects have defined an overall form that is then broken down into a series of smaller segments that are fitted together through a set of adjustments.

Pre-Rationalized Geometry

"*Pre-rationalisation* is a bottom-up or generative method where the parts are defined and building geometry is a result of combining these."[23]

Woodbury highlights the unbuilt White Magnolia Tower in China by Kohn Pedersen Fox as a good example of the inherent benefits found in the pre-rationalization of geometry. As a firm, KPF has continually used a pre-rational approach with projects in their specialized Computational Geometry Group.[24] The White Magnolia is considered pre-rational because of its use of a recurring toroidal section, which keeps an unchanging form across a series of multiple panels instituted during "design development studies… [these] centered on the idea of generation and use of parametrically controlled torus patches… [which] can be subdivided into flat quadrilaterals. These quadrilaterals can be interpreted as flat panels for curtain-wall construction."[25] This decision was made because "…when geometry is incorporated early into the design process [as a pre-rationalization]… geometry and form become form-making ideas in their own right."[26] At the scale of a tower this size, developing an overall digital construction scheme becomes a viable intent alone.

In summary, the main properties of pre-rational parametric design include a bottom-up approach where geometry is generated, a situation where parts are defined and building form results from combining these, establishing a rational geometric method during conceptual stages, defining how the design rules develop, and allows the computer to become a generative/optimization tool.

Post-Rationalized Geometry

"*Post-rationalisation* is a top-down approach where the final geometry is defined and the parametric design task is to find rational geometry that gives a very close match."[27]

Woodbury highlights the Elephant House at the Copenhagen Zoo (Figure 5) as a as an excellent example of the flexibility found in post-rationalized geometry. Designed by Foster + Partners and completed in 2008, the project also uses a portion of the toroidal section as an initial design form, "…with all successive structural/glazing decisions relating back to it."[28] The process created a series of 26 variable effects on the shape that would break it down into a series of panels using "…structural centerlines, as well as beam and glazing elements, [that] derive from the torus geometry."[29] Using these centerlines, "…the structure generator produced all of the centerlines, primary, secondary, tertiary, quaternary structural members, glazing components, as well as tables of node points."[30] With this level of detail applied *parametrically* rather than *directly*, the exact shape of the toroidal section could be manipulated according to new information in the design process, yet adjust itself into the buildable script previously outlined as generated from the inherent logic of the tori.

In summary, the main properties of post-rationalized parametric design include a top-down approach where geometry is already defined and create a situation where parametrics try to find rational sub-geometry that matches closely to the pre-defined geometry. It is largely considered after the conceptual design phase, defines how the design develops, and allows the computer to become a refinement and complexity-management tool.

The Effects of Pre-Rational vs. Post-Rational Geometry

From the examples, it is apparent that the rationalization choices in parametric geometry become central to the overall scheme of the project. Hudson explains that the "…embedded or pre-rational as a generative process [exists] where the geometry emerges as a result of understanding the rules that define it. This is in contrast to a post-rational approach where rules are sought that define a specific form"[31] – post-rational therefore searches for rules that are applied to a form, while pre-rational searches for rules that define the form. If we hold this to be true, then a post-rational strategy (as an independent applied form-finding exercise) is more reliant on the designer's intuition rather than a deeper application of truly parametric design. In historical contrast, the earliest applications of parametric design (particularly Sullivan, Gaudi and Moretti) were decidedly pre-rational. Initial attitudes toward these methods were based on creating explicit solutions to a defined problem – this arose out of an analytical thinking towards parametrics as a skilled technique rather than a formal exercise.

As parametricism has flourished, particularly into the 21st century, it appears to have become more and more common for post-rationalised methods to be used on projects that have not been designed with significant pre-rational intent. While this is giving way to a much broader use of parametric design across a variety of platforms, the suitability of these processes have recently been questioned by some leading practitioners. In particular, Greg Lynn and David Rutten have questioned the direction that parametric architecture has taken in recent years, for similar yet distinct reasons. As the creator of the Grasshopper software platform, Rutten raises warning flags primarily in the academic setting when students are beginning their first explorations into parametric architecture, focusing exclusively on Grasshopper applications. He laments the fact that with the progressive ease in creating parametric definitions, students can "…make a geometrically involved algorithm in just a few minutes…"[32] without understanding fully the implications, positive and negative, of this particular process. This leads too often to situations "…where complexity masquerades as information… [where] computation can be used to generate large amounts of complexity, but complexity does not equal worth."[33] Similarly, Lynn expresses the need for restraint from unintended designs by creating a primitive or base model that address the design problem directly through a series of families. These act simultaneously as "…the definition of a primitive, rather than an origin is critical in this approach… [it] defines a dialogue between a more generic whole and a collection of continuously defined parts."[34] Lynn's definition not only speaks to the benefits in a highly intended version of designing with parametrics (considering the whole relating to the parts simultaneously, and vice-versa), but is also a decidedly pre-rational way of thinking: his integrated approach only works when the base-geometry relies on a thought-out method that addresses the design problem.[35] Both Rutten and Lynn end up arguing towards the same point: currently, the relative ease of using parametric design software has expanded the field immensely, and often in positive ways, but it has also removed many fundamental understandings of their use. As this basis can now be bypassed easily with the interactivity of software, something that was once considered not just a necessity, but the entire *raison d'etre* of the technique, has fallen by the wayside. When used appropriately, post-rational applications of parametric software can produce elegant solutions to tough design problems (as shown in Foster + Partner's Elephant House, Figure 5). But they have also given designers a default method to use parametrics superficially, often when it is not necessary. Lynn opines that "…the articulation – if not the expression – of structure is considered in the very first moment of design, with the selection of a geometric type and the effect this has on the surface form and panelization."[36] Without understanding the geometric decisions and intentions in the design, this often leads to "crude skin-on-rib panelization."[37] To corroborate this point, Rutten firmly states, "…the only time it makes sense to invoke computation in the design process is when there is some relevant data that needs to be computed."[38]

The problems that Rutten points out appear to criticize post-rational design methods rather than pre-rational. Complexity can be added via parametric post-rationalisation to any form *ad infinitum*; however, the same cannot be said for pre-rational, since pre-rational relies on the addressing of a specific problem (i.e. data) with direct manipulation from the outset. It is intricately linked to the design intent. When Lynn describes a need for choosing the geometric origin according to intentions, he is accounting for the fact that in doing so, the designer can remove the geometrically inappropriate choices from his described expanse of possibility from the initial primitive and narrow the project's focus to a specific set of families or variations.

Learning From Las Vegas - Learning From Parametrics

As parametricism moves forward in contemporary architectural discourse, the ongoing shift towards a parametrics of aesthetic rather than a parametrics of technique appears to draw parallels to Venturi and Brown's theories of architectural symbolism in Learning from Las Vegas. This is particularly evident in their rationalization of symbolic form and the parametric rationalization of geometry. In both, the intent of the architect becomes the pivotal point of departure in determining whether decisions take place before or after addressing the design problem. Venturi and Brown propose two archetypes of building, i) the Duck and ii) the Decorated Shed:

> I) Where the architectural systems… are submerged and distorted by an overall symbolic form. This kind of building-becoming-sculpture we call the duck.
> II) Where systems of space and structure are directly at the service of the program, and ornament is applied independently of them. This we call the decorated shed.
> The duck is the special building that is a symbol; the decorated shed is the conventional shelter that applies symbols.[39]

Due to the broad intent in creating these definitions, Venturi and Brown suggest that all construction can essentially be sorted into one of these camps, and sometimes a building will have elements of both. Additionally, Venturi and Brown take a disinterested approach to these definitions: they do not favor one over the other, and neither is the 'right' method of designing compared to the other. Both Ducks and Decorated Sheds arise from specific intents in their conception: was the building originally conceived as a Duck, and therefore displays the literal, honest version of its interior function outwardly? Or was it conceived as a Decorated Shed, with a message of interiority applied directly onto it independent of the construction? (Figure 6).

Alternatively, to posit the previous question in a parametric framework: Is the building conceived of pre-rationally, to respond to a design problem with an appropriate formal technique? Or is the building conceived post-rationally, with a parametric system applied to a parametrically or non-parametrically generated aesthetic form? The Duck might be considered a pre-rationalized symbol because its form emerges from analyzing how to literally communicate the message for a shop that sells ducks and/or eggs. Meanwhile, the Decorated Shed might be considered a post-rationalized symbol because it emerges from the independent application of signage to structure. Venturi and Brown reinforce their ideas by affirming that "…architecture may be ordinary – or rather, conventional – in two ways: in how it is constructed or in how it is seen, that is, in its process or in its symbolism."[40] If this is assumed, then it is also reasonable to assume that "…it is the contradiction… between image and substance that confirms the role of symbolism and association…" both in modern and parametric architecture.[41] This leads to Venturi and Brown's definitive argument: "It is alright to decorate construction but never construct decoration,"[42] reaffirming the notion that design intent must be established and followed before formulating a parametric approach.

Finally, if it is true that post-rationalized parametric architecture is indeed a decorated shed, which Venturi and Brown indicate as "… the applique of one order of symbols on another,"[43] it is reasonable to suggest that with the vast potential afforded by cutting-edge parametric tools, users should strive to achieve something greater than simply an appliqué on top of the designer's whim. Rather, as Venturi and Brown note, we should avoid pursuing "… what appears on the surface as a hard, rational discipline of design, [but in fact] turns out rather paradoxically to be a mystical belief in the intuitive process."[44] It is therefore fair to conclude that while both pre-rational and post-rational methods serve a direct function in specific situations, there is more potential for post-rational parametric architecture to stray from the roots of the technique. This appears to move towards an aesthetic that may not necessarily live up to the potential that parametricism has in shaping the architectural profession of the future. Pre-rational parametric design inherently allows the parametric intent to become the symbol; the technique is the aesthetic. Post-rational intents leave open the possible fallacy to apply parametric symbolism after the fact; the aesthetic is not necessarily the technique.

<u>Conclusions</u>

As parametricism is an on-going movement in architectural circles with both regional and global trends, it is unrealistic to predict the direction it will take and its implications for becoming established in the mainstream profession. However, establishing an understanding of the subject, and the current transition it is undergoing from design technique to aesthetic, can steer attitudes around parametricism into a more understandable direction. The history of parametric architecture points towards a devotion to technique, allowing a particular pseudo-scientific approach to the discipline that was not as accessible previously. The shift moves to a question of the relationship between different parts – originally these affiliations were technical, but they now appear to be moving moreso into a realm of visual considerations as well.[45] While it is understandable that an identifiable, complex imagery like parametrics will begin to morph as it evolves to encompass a broader spectrum of architectural practice, it is important that it remain true to its origins. The forced use of parametric design strategies in unnecessary projects only weakens the movement as a whole, and the possibilities parametricism holds are too great to be ignored in favor of only aesthetic considerations. It is therefore vital that while parametricism is becoming a new form of symbolism, the honesty in this symbolism (regardless of its rationalization) must stay true, similar to Venturi and Brown's lessons from *Las Vegas*. The transition needs to move from the previous dogma of searching for a solution to searching for a message within the solution. If this happens, coupled with the vastness of its applications, Parametricism can potentially emerge as one a defining movement for the next generation of architects.

Endnotes

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[23] Ibid, 235.

[24] Ibid, 89-90.

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[26] Ibid, 171.

[27] Ibid, 235.

[28] Woodbury, *Elements,* 69-70.

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[30] Ibid, 73.

[31] Hudson, *Strategies,* 90.

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[36] Rappolt, *Greg Lynn Form,* 28.

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[39] Dennis S. Brown, Steven Izenour and Robert Venturi, *Learning From Las Vegas* (Massachusetts: MIT Press, 1977), 87.

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[41] Ibid, 137.

[42] Ibid, 163.

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[44] Ibid, 134.

[45] Schumacher, "Design is Communication," 12-3.

Images

Figure 1. Patrik Schumacher, “Kartal-Pendik Masterplan,” digital rendering, 2006. http://www.patrikschumacher.com/Texts/Parametricism%20%20A%20New%20Global%20Style%20for%20Architecture%20and%20Urban%20Design.html

Figure 2. Greg Lynn, “Vienna OMV Corporation,” digital rendering, 1996. http://glform.com/buildings/h2-house/

Figure 3. Luigi Moretti, “Model of Stadium N,” photograph of physical model, 1960. http://www.danieldavis.com/a-history-of-parametric/

Figure 4. Antoni Gaudi, “Hanging Model for Colonia Guell,” photograph of physical model, undated. http://www.danieldavis.com/a-history-of-parametric/

Figure 5. Brady Peters, “Structure generator interface and generated geometry,” digital rendering, 2008 and Robert Davies, “Interior of the main herd enclosure in the New Elephant House,” photograph, 2008. http://www.bradypeters.com/uploads/1/6/2/9/1629522/64804_orig.jpg

Figure 6. Dennis S. Brown, & Robert Venturi, “The Duck and the Decorated Shed,” sketches, 1972, http://www.arch.mcgill.ca/prof/sijpkes/arch374/winter2001/mwildm/ducktl.gif http://www.arch.mcgill.ca/prof/sijpkes/arch374/winter2001/mwildm/decoratedshedtl.gif