Curating Complexity

The Role of Sentience in Parametric Design

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The Role of Sentience in Parametric Design

by
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Similar to how the industrial revolution and mechanized manufacturing processes spawned the engineer's aesthetic, modern computational tools have brought forth an architectural culture where notions of expression are suppressed in favour of design justification.

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The Role of Sentience in Parametric Design

Antonio Cunha, M. Arch, 2016
Master of Architecture, Ryerson University

Abstract

In De Architectura, Vitruvius makes note of three criteria that define architecture; firmitas (durability), utilitas (function) and venustas (delight). These ideals form the philosophical foundations of virtually all modern architectural theory. With the advent of computational tools, many advocates, commonly armed with staggering statistics, frame these methods as a means of increasing efficiency in collaboration, construction and performance - muting the critical role of a sentient designer in architectural discourse of the digital age. The role of the parti has eroded in favour of computational strategies that constrain utilitas to a measure of quantifiable “fitness”.

The research herein unveils and reflects upon the mutating role of the architect in computational design, advocating for the importance of qualitative reasoning in a parametric process. Where the current paradigm is negligent, the project aims to illuminate and reinforce the role of today’s sentient designer nested in a cultural milieu of computation.

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Introduction

Computation has revolutionized all facets of contemporary society. From the way goods are purchased to how information is accessed, to how society communicates, the personal computer has transformed contemporary life into an age where digital literacy is fundamental to existence. This technological revolution has instigated a complete restructuring of the current professional culture; spawning new professions, mutating professional roles, and spelling the demise of entire industries. Employees are faced with keeping up with a constantly evolving array of digital tools that are simultaneously advancing and fragmenting the professional landscape. The architecture, engineering and construction (AEC) industry is no exception to these technological repercussions. Digital design tools have reshaped how all parties involved in building procurement communicate, collaborate and construct. Every client, architect, engineer, consultant and builder is experiencing major shifts in both their mode of practice and professional responsibility. The architect, situated at the center of this rapidly evolving paradigm continues to be profoundly affected by these technological advancements.

Over the past two decades, computational design strategies have had profound consequences on the profession, the nature of architectural ideation and the role of architecture in culture. From the mass adoption of AutoCAD in the late 1980s and early 1990s to the complex digital databases employed today, the tools available to architects and the AEC industry at large are constantly expanding the realm of possibility. Architects now must realign their efforts toward design strategies centered on computational processes. These technologies have given rise an wide swath of theorists proclaiming this the opportune moment for the architect's reassertion as a central component in the design and construction process.

Not only has the design team become much more diverse, but the buildings, materials, systems and technology involved in today's design and construction are also more sophisticated than ever before. The method of describing and building a project is more complex because digital information can be extracted, exchanged and applied quicker and more efficiently than ever previously possible. Until recently, these tools had simply reshaped the architect's method of producing two-dimensional drawings, however with the advent of Building Information Modeling (BIM), computational methods have reshaped the design process itself as well as the architect's end product. These topical technologies can no longer be considered "another pencil"; they are both evidence and agents of fundamental shifts in the nature of architecture. (Scheer, 2014)

With the rise of computational design, formal strategies have emerged based on the use of computable functions to ensure superior building performance in an effort to quantitatively justify design quality. Architectural culture has become saturated with theorists and practitioners praising the ability of these tools to improve building performance and construction quality. These formal strategies effectively constrain architectural *utilitas* to a measure of fitness derived from an algebraic combination of quantifiable entities. (Kotnik, 2010, 1-16) Enabled by computational simulation, current architectural practice is experiencing a shift toward performance-driven design. Architects and designers often tout their proposals' ability to control daylighting, reduce energy consumption or provide superior interior comfort in lieu of its expressive or formal quality. Formal expression whether consciously imparted or not, is suppressed in favour of quantifiable justification, rendering the topic of expression as a taboo in contemporary architectural discourse.

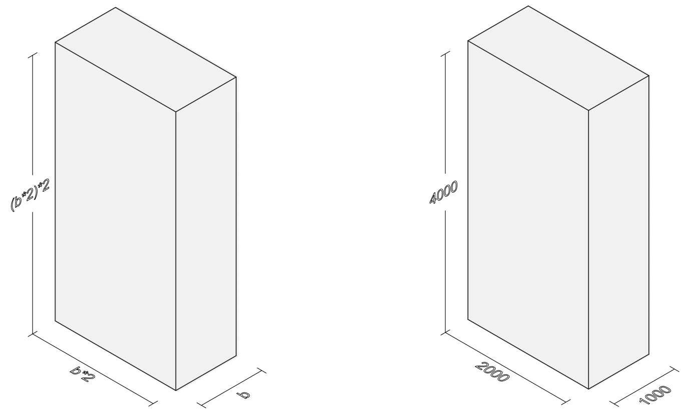


Figure 01
Metrics and Logics

Current computational strategies employed in architecture are commonly driven by parametric modeling tools. Parametric design can be described as a process that enables the expression of parameters and rules that, together define, encode and clarify the relationship between design intent and design response. (Jabi, 2013) Rather than describing the object with a defined set of metrics, the product is described through abstract interconnectivities. If one were for example to describe a rectilinear mass with a width of ten units, depth of twenty units and height of forty units, in a parametric mode of ideation, this same mass would be described as a width of 'b', a depth of 'b*2' and a height of '(b*2)*2'. As such, it is clear that parametric modeling has had a major impact on not only what the architect represents and produces, but the process in which one conceives of the artifact. Fabian Scheurer of DesigntoProduction makes note of this mutation of architectural thinking with, "The information of a thousand drawings can be reduced into one well defined algorithm and a thousand small sets of only a few parameters. But again, this trick poses new challenges. First you need to know how to program. Designers, especially well prepared to deal with ambiguous ill-defined problems, suddenly have to come up with unambiguous, well-defined formal descriptions." (Scheurer, 2010, 86-93) The "work" of architecture has thus shifted to a higher level of abstraction. Architects must now conceptualize their designs through a speculative logic, tailored to a specific purpose, however flexible enough to accommodate a wide array of possible variants.

The resultant ability to produce large amounts of random sampling affords the opportunity to explore multiple solutions, some of which would never have been conceived by the designer. Parametric modeling tools provide the potential for the designer to magnify their intellectual and inventive capability, just as machines and automation magnified physical capacity in the nineteenth century. (Alexander, 1964, 11) Human decision making can be characterized as arbitrary, authoritative and often naive, whereas parametric schemes celebrate complexity, consistency and generality, resulting in the emergence of designs that while functional, may be unanticipated by the designer. This possibility reveals more potential than ever before; as opposed to purely human-based intelligence in resolving design problems, a complementary synergistic relationship between the design and computer becomes possible. (Gleiniger, 2008)

From one perspective, one could argue that these digital processes are poised to eventually spell the demise of the designer. However deliberate design remains a crucial component. Architectural design negotiates complex programmatic requirements via a series of steps, often prior to formalizing a specific design goal. Whereas the goal of other design fields is to solve the problem through the best possible means, architecture is open-ended, flux and uncertain. (Gleiniger, 2008) Naturally, there is a limit on the number of distinct concepts which a designer can manipulate cognitively at any one time, therefore one forced to re-encode these items. (Alexander, 1964, 143-152) The designer establishes a hierarchy of notations to process complex information. In a parametric design process, the designer must untangle interdependencies and discover sets of rules that are as simple as possible while flexible enough to allow a myriad of design variations. (Sheurer and Stehling, 2011) Therefore the ability of parametric techniques to generate new designs is directly tied to the designer's perspective and cognitive abilities, because continuous, transformative processes ground the emergent form in qualitative cognition. (Kolarevic, 2003, 11-28) The designer iterates the designed system, imparting their unique aesthetic and plastic sensibilities on every decision in the process. The parametric logic is simultaneously interpreted and manipulated in a self-reflective process where the resulting virtual model plays a critical role in the designer's evolving design goals.

Architectural decisions no longer solely take place in deriving relationships between components, but rather in consciously determining what relationships to consider. Parametric design is not necessarily about the formalization of design process or the automation of decision making, but about the relationship of formal processes with architectural thinking. (Kotnik, 2010, 1-16) As opposed to an authoritative relationship between the designer and the computer (or vice versa), establishing an iterative dialogue between the human and machine is paramount in computational design.

The Traditional Process

In the traditional design process, the architect is tasked with a design challenge, loaded with an extensive swath of functional and formal considerations. From an active acknowledgment (or purposeful neglect) of these considerations, the designer formulates a concept; in their view, an appropriate expressive intent for the project at hand. However, this is not to be confused with the method employed the achieve the designer's pursuits. For example, if the intent is to create a mass seemingly floating above the ground plane, this could be accomplished by a variety of means, ranging from the incorporation of a mirrored structural mass below, a magnetic force field levitating the mass above or suspending the mass via an inconspicuous structure above. Regardless of the method employed, the basic intent of the design remains constant - to represent this figure seemingly defying the laws of gravitation.

Following the establishment of an expressive intent, the designer divides these considerations into automated and conscious responses. Christopher Alexander, refers to these two categories as unselfconscious (automated) and self-conscious (conscious) approaches. Alexander defines his selfconscious response as, "an approach in which the individual designer's personal, fashionable or otherwise preconceived ideas are arbitrarily imposed upon natural patterns of human behaviour." (Alexander, 1964, 143-152) It is within the selfconscious design activities that the form-maker asserts individuality and expression.

Conversely, in the unselfconscious system, the designer acts as no more than an agent. The unselfconscious realm is where matter organizes itself coherently according to an evolutionary process of adaptation in response to environmental feedback. (Alexander, 1964, 143-152) Here, the designer becomes a conduit for the flow

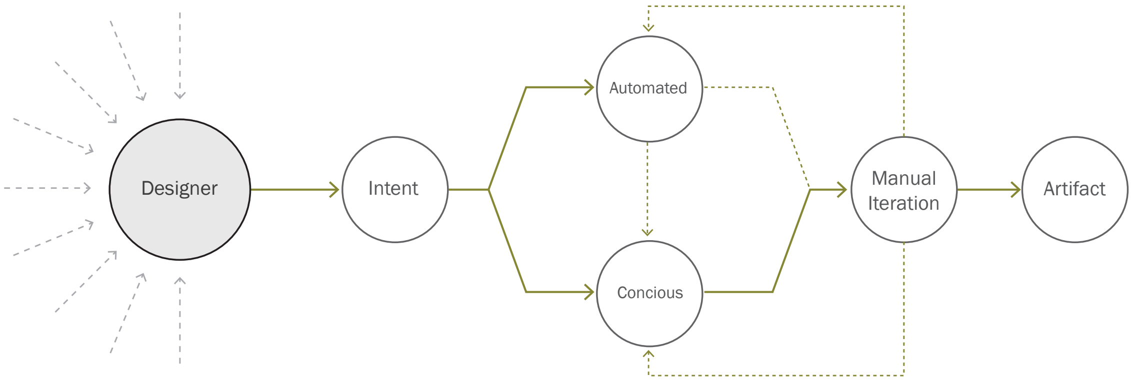


Figure 02
The Traditional Process

of information between the problem and the solution, with the aim of achieving “good fit” between the object and its context. By identifying automated (unselfconscious) considerations of the design - elements not pertinent to manifesting expressive intent – the designer avoids the challenge of constant decision making by formulating and implementing rules to relieve the burden of self-consciousness and of too much responsibility. (Alexander, 1964, 143-152)

Continuing with the example of the ‘levitating’ building; materiality, structure and vertical circulation would likely be unselfconscious considerations. In contrast, interior finishes, roof assemblies and entry locations would likely fall in the realm of selfconscious responses, as they can generally be considered as evolutionary adaptations to the subjective decisions made in the unselfconscious realm.

The design process then proceeds through a series of manually produced iterations where each is evaluated with respect to how it satisfies both selfconscious and unselfconscious considerations. Through these iterations, the designer reviews the ‘appropriateness’ of each instance, often resulting in the migration of some design considerations from selfconscious to the unselfconscious and vice versa while evolving the original expressive intent. In the case of the floating building, one can argue that by deciding to create a magnetic force field to hold the building mass above the ground plane, there would potentially be significant weight limitations, potentially impacting design decisions that were previously relinquished to the unselfconscious realm. After a process of push and pull between considerations, the designer generates a scheme that ‘fits’ the given subjective and objective criteria. This final product is ultimately the result of a non-linear, cognitively-based cross-referencing in a complex network of design considerations and prioritizations.

The Parametric Process

Parametric design strategies share many of the same characteristics as their traditional counterparts. As with any creative undertaking, the designer is bombarded with countless contextual considerations. From these factors, a design intent is conceptualized. Similar to the traditional design process where factors are delegated to automated or conscious responses, the designer prioritizes and establishes a hierarchy of design factors to consider in accordance with their expressive intent. These factors can be both objective and subjective. They can include quantifiable aspects such as lot zoning limitations or subjective factors affecting the appearance of the object such as proportion or degree of symmetry. Where qualitative factors are considered, the designer must develop a system in which to quantify and integrate these considerations within the parametric model.

Where this process differs greatly from that of the traditional paradigm, is in the formulation of an abstract logic aimed at establishing the design intent. Christopher Alexander explains logic as being, “concerned with the form of abstract structures, involved the moment we make pictures of reality and then seek to manipulate these pictures so that we may look further into the reality itself.” (1964) This organizational structure is a way of representing the design problem in an effort to make it easier to solve. The logic reduces the gap between the designer’s limited cognitive capacity and the daunting scale of their task.

From these automated and conscious considerations, the designer develops an abstract framework. This guiding logic becomes a codified sequence of actions permitting a wide degree of variations, all of which remain true to the given design criterion. This tasks demands a significant level of human cognition, both in anticipating

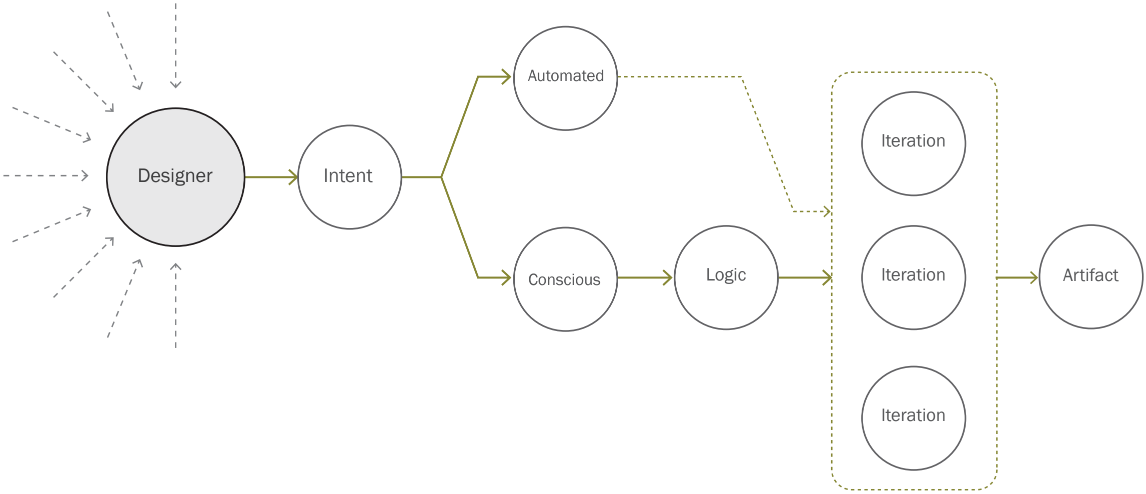


Figure 03
The Parametric Process

how the logic will respond to a differential inputs and in the curation of how these considerations are integrated toward optimal efficiency in realizing the desired response. Following the development of this logic, a series of iterations are generated - varying outputs derived from varying inputs. These iterations, while computationally generated to satisfy all indicated criteria, are then once again subjected to cognitive interpretation. The designer evaluates the outcomes based on the satisfaction of automated considerations. These, combined with open ended, subjective criteria form the basis of selection from a resultant field of computationally generated variants.

In many cases, the output of the computational scheme demands a modification of the logic itself. For instance, if there is oversight in how particular geometries indirectly affect other critical aspects of the design, or the actual resultant of the definition does not satisfy the fundamental criteria of the design intent, the designer must refine the interdependencies rooted in the framework, permitting access to a new field of samplings. Once the logic produces a series of appropriate design solutions, the designer is to select a final scheme. Again, this requires human intelligence to judge for the best “fit” based purely on qualitative reasoning as every design variant theoretically satisfies the stipulated objective design criteria.

The designer’s qualitative assessment and design sensibility is therefore equally as critical in the computational process as it was in the traditional design paradigm. The designer still conceptualizes, prioritizes, rationalizes, evaluates and makes selections throughout the process, actively engaging in a mutually informative dialogue with the computational tool.

01 | Expression

For centuries, theorists have attempted to rationalize and define the essential components of creating aesthetic grandeur in all types of creative undertaking. It is human nature to distill and provide clarity or meaning to a topic so complex and subjective. Despite these unwavering efforts, only one statement remains universally true; beauty is an enigmatic term. Perhaps this struggle to explain and order such a sophisticated notion is no more clearly evidenced by the extensive collection of terms that philosophers and theorists alike have attempted to make synonymous with Vitruvius' *venustas*. Many have been consumed by this constant search for 'truth', 'order', 'life' and 'beauty', yet none have successfully articulated the factors dictating a superior aesthetic with any remote specificity. It is with this consideration that one must employ the term 'expression' to appropriately evaluate design success, for expression is not bound by universal criteria, but rather is open-ended; describing the manifestation of an idea, concept or feeling imparted by an individual, a group of individuals or a society at large.

Expression can be considered the amalgam and result of decisions, actions and gestures imparted throughout a design process informed by both personal and environmental context. Expression comes to light through the rationalizations and prioritizations embedded throughout the design process regardless of the tools or methodologies employed.

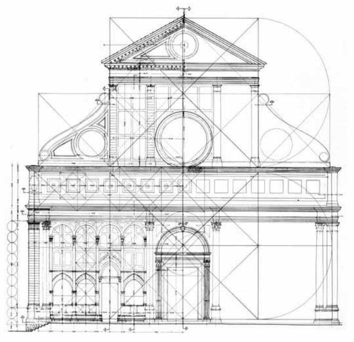
'Style' however, is a much more recent concept. The term first entered architectural discourse in 1828 with Heinrich Hübsch's pamphlet entitled "In what style should we build?" (Schumacher, 2011) Although widely contested by many theorists of the era, Hübsch introduced the concept as a central point of discussion in architectural discourse for the next century. Many argue that style is a retrospective categorization

– a designation founded upon reflection and understanding of an era, not a speculative framework for how 'best' to design. From the former perspective, one could consider style take place at varying scales; individual style, regional styles or epochal styles. (Schumacher, 2011) Style therefore shares many of the same characteristics as expression. While the former refers to the post-interpretation and categorization of an object based on formal qualities, the latter refers to the ideals consciously symbolized and captured within such object.

While the general demands of utility and beauty have remained consistent since they were first written by Vitruvius, style - the principles guiding the application of formal values - has evolved in unison with historical demands. (Schumacher, 2011) The adaptive evolution of architectural discourse has progressed through a historical succession of styles structured by a constantly mutating, recursive set of expressive principles.

Traditional Interpretations

The foundations of virtually all modern architectural theory were first laid in 27 B.C. by Vitruvius in his Ten Books on Architecture. The classical architect and first known writer to develop a theory of architecture, makes note that in order for a built work to be considered 'good' architecture, the structure must be built with due reference to durability (firmitas), convenience (utilitas) and beauty (venustas). (Morgan, 1960, 17) Despite initially being transcribed in the first century B.C., Vitruvius' architectural theory gained notoriety and relevance only during the renaissance era. Italian architect and polymath, Leon Battista Alberti whom effectively formalized the architectural profession in the 15th century, referred to Vitruvian ideals and studied ancient Roman remains, publishing his De Re Aedificatoria (On the Art of Building) in 1485 – a manifesto and guiding framework for the Classical style.



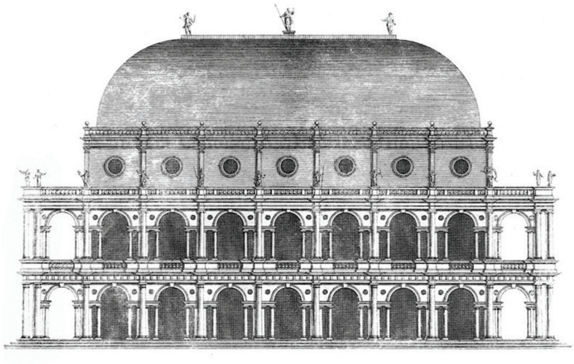


Figure 04 [Left]
Elevational study of Basilica Santa Maria Novella designed by Leon Battista Alberti

Figure 05 [Right]
Elevation of Basilica Palladiana designed by Andrea Palladio

Classicism claims to be the one and only true form of architecture. The classical style finds its justification in religion, thus placing architectural theory outside of historical bounds. As God's existence is eternal, the classical style was seen as a means of true order unbound and undefined by time or technology. The style was therefore thought to be both universal and eternal. (Winters, 2007)

Classical architecture is considered, roughly, to be that constructed in or derived from the ancient world. Building elements exist in a number of typical orders, each with its own internal logic and guiding principles. Classicism is founded on the notion that architecture is a form of mimesis. Architecture, from the classicist's view, is imitative and symbolic of the primitive shelter and its method of construction. (Winters, 2007) The abstract elements of the primitive shelter are formalized in enduring materials governed by a rigid logic. The classicist's geometric library is strictly platonic - symmetry and geometric rationale are celebrated, while repetition and imitation are favoured over variety and uniqueness. Classical adherents viewed this demanding geometric logic and invariation critical to establishing true order in the eyes of god.

By the early 19th century, Classical theories of art and architecture gave way to a new formal thinking ushered in by the values of the enlightenment era. The enlightenment era refused to be limited by the Renaissance's conventions of the rational and the logical as the only form of truth. It was a time that saw the cross-pollination of topics previously operating in isolation from one another; scientific knowledge with artistic expression, art with politics, poetry with mathematics and nature with built form. (Andersson, 2014) The rise of empirical intelligence steered architectural practice away from traditional Euclidean forms and toward biological and material focuses. (Picon, 2011, 28-35) Expressive ideals in art and architecture no longer existed as godly commandments, but rather as intellectual responses to the materials and technologies of the time - reality replaced piety.

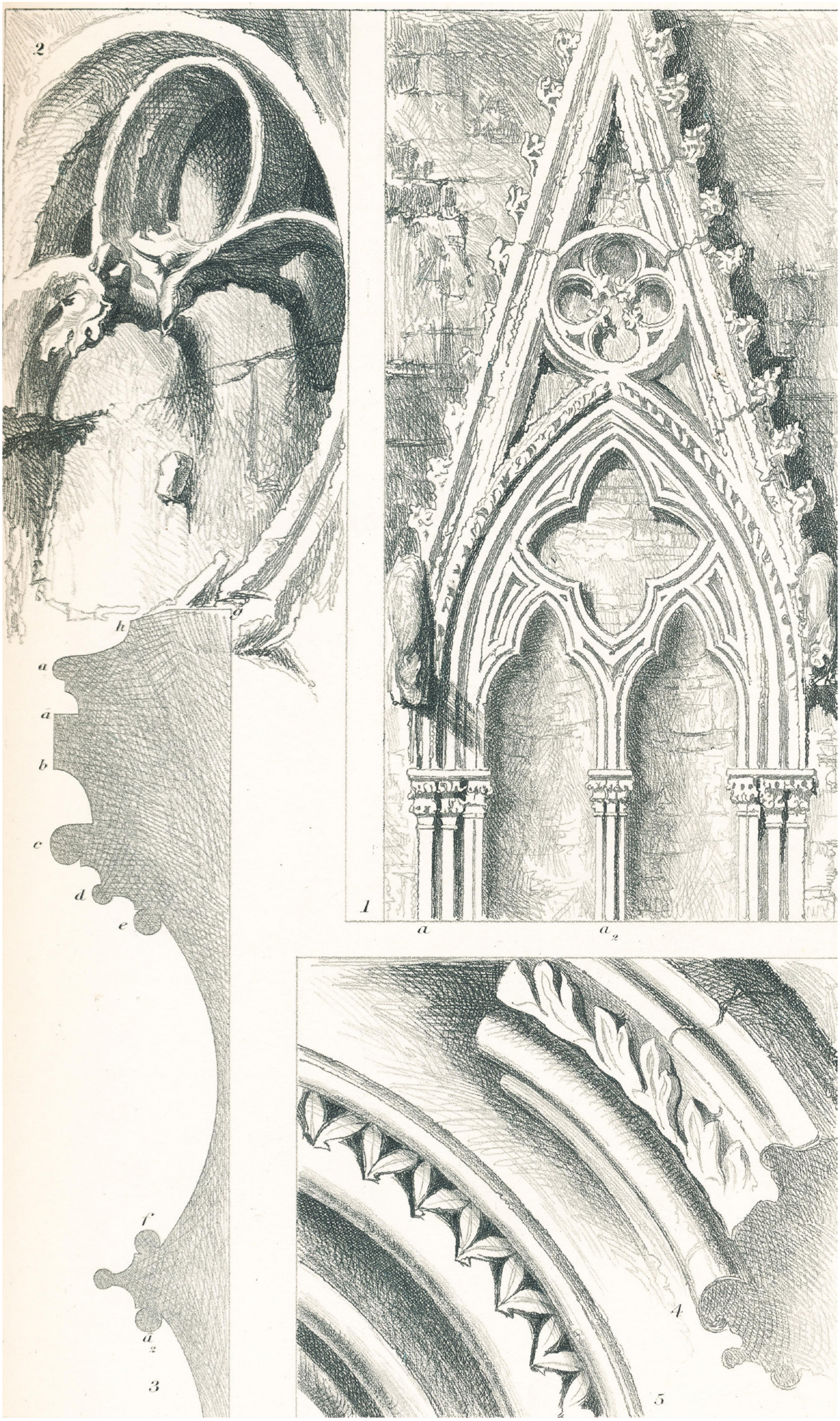
John Ruskin, arguably one of the most influential theorists of the time, wrote extensively on how the organic beauty of naturally occurring phenomenon can inform artistic and architectural expression. In his argument for a return to the Gothic Style, Ruskin proposed this framework based on the new-found complementarities of the enlightenment era, deriving relationships and justifications for art and architecture from scientific, mathematic, social and natural principles. Ruskin's manifesto for the Gothic style, The Seven Lamps of Architecture, identifies, sacrifice, truth, power, beauty, life, memory and obedience as the components to a healthy society capable of generating 'good' architecture. (Ruskin, 1849) In contrast to classicism, a recurring theme in the Gothic Style was the role that variation played throughout several dimensions of its art and architecture. In his Stones of Venice (1851), Ruskin makes constant reference to landscapes and other natural examples to demonstrate the importance of variety to expressive value. He explains this fundamental criterion with:

> *...change or variety is as much a necessity to the human heart and brain in buildings as in books; that there is no merit, though there some occasional use, in monotony; and that we must no more expect to derive either pleasure or profit from an architecture whose ornaments are of one pattern, and whose pillars are of one proportion, than we should out of a universe in which the clouds were all of one shape, and the trees all of one size. (175)*

Ruskin references the flexibility and consequential variation of Gothic architecture as the defining attribute of its stylistic superiority. Where Classicism prescribed form, the Gothic framework offered an indeterminate field of possibility. Taking for example the classic arch; the classicist would prescribe its geometry as a single continuous arc bound by a rigid relationship between its width and amplitude. The Gothic arch's composition however, is inscribed within three mobile points in space allowing a wide range of topological variation. The Gothic arch could be narrow and tall or wide and shallow while still satisfying the abstract stylistic criteria. Ruskin therefore, long before the advent of the personal computer, was one of the first theorists to advocate for the role of topological thinking in architecture.

The variability of the Gothic style also stemmed from a completely altered sense of compositional design thinking. Whereas Classicism was elemental in that pre-existing components were arranged in a rigid sequence, the Gothic celebrated continuity between elements, deriving its beauty from variation produced by interconnected building elements. Variety and inter-connectivities have become prominent concepts in architectural discourse, re-emerging as a central point of discussion in today's digital age.

Figure 06
Ruskin's Study Sketches of Gothic Cathedral Windows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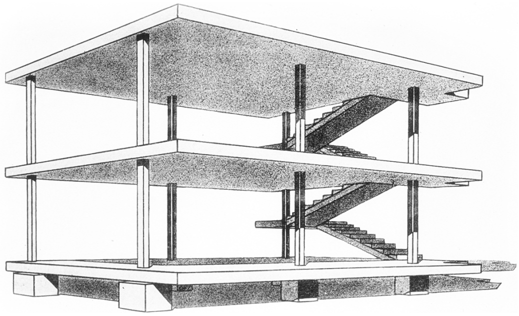
Expression of the Machine Age

The automated tools and manufacturing processes that emerged during the early 20th century stimulated a rapid, yet significant paradigm shift in architectural expression; the rise of the Modernism. The foundations of modernism were founded in the union of architecture and industry characterized by a new image of modern living coupled with a propensity for exploring new materials and techniques. (Bergdoll, 2008) While Ruskin had previously advocated for the role of the dignified craftsman in the creation of architecture, by World War One, manufacturing tools and processes spawned an architectural culture distinguished by rational forms and utilitarian ideals. Under these circumstances, the Modernist style was proposed on logical and economic grounds as opposed to the aesthetic or symbolic representation so prominent in previous eras. (Banham, 1960)

The modernist aesthetic is viewed as a derivative of the building's function and the technologies employed in its construction. Le Corbusier, arguably the most influential architectural theorist of the modern era declared, "Man's stock of tools mark out the stages of civilization, the stone age, the bronze age, the iron age. Tools are the result of successive improvement; the effort of all generations is embodied in them. The tool is the direct and immediate expression of progress" (Goodman, 2007) Expression therefore assumed a different role during the modernist era –the term no longer pertained to abstract embellishment or representation in physical form, but rather the building's guiding logic to its function and assembly were the subject to be expressed. The task of the designer was not to express oneself and one's feelings in a subjective way; it was to create harmonious objects to serve evolving societal demands. (Bill, 2010)

Published in 1923, Corbusier's *Towards a New Architecture*, emerged as a manifesto for modernism – anchored by a chapter he titles the 'The Engineer's Aesthetic'. The author argues that in an age of machinery and automated manufacturing, the engineer's ideals of rationalism



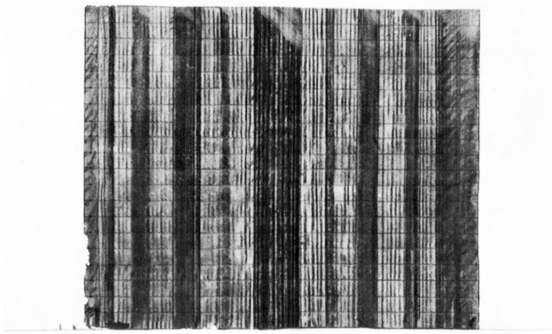


Figure 07 [Left]
Standard Column and Slab Structure for Corbusier's Mass-Produced Domino House Project

Figure 08 [Right]
Concept Elevation of Mies Van Der Rohe's Friedrichstrasse Skyscraper Project in Berlin, Germany

prevail in meeting the demands of society, proclaiming architectural discourse in a state of disillusion and the engineer as the form maker of the future. (Goodman, 2007) However, Corbusier does not necessarily discount the role of expression or qualitative decision making, as he mentions, "the engineer has his own aesthetic, for he must, in making his calculations, qualify some of the terms of his equation; and it is here that taste intervenes." (Goodman, 2007) Corbusier elaborates on his conception of the engineer's aesthetic with:

> *It is that architecture, which is a matter of plastic emotion, should in its own domain begin at the beginning also, and should use those elements which are capable of affecting our senses, and of rewarding the desire of our eyes, and should dispose them in such a way that the sight of them affects us immediately by their delicacy or their brutality, their riot or their serenity, their indifference or their interest; these elements are plastic elements, forms which our eyes see clearly and which our mind can measure. (16)*

Corbusier argues that the modernist style therefore does not neglect form, but rather derives its expressive value from rationality and technological comprehension. Modernist architecture was to engage aesthetic understanding by a functional prescription of form. (Colquhoun, 1981, 252-255)

By World War Two, modernist ideals gained mass popularity as urban centers demanded new planning strategies to address poor living conditions instantiated by increasing poverty and mass destruction and neglect of urban infrastructure during the war. Many projects of the modernist era were initially successful, causing the public to associate the engineer's aesthetic with prosperity and progress. In the post-war era, the movement's ideals of social responsibility were considered so progressive that the Architectural Review proclaimed modernism, "the style of the century". (Davis, 2013)

By the 1970s, critiques of Modernist planning and design sensibility began to gain traction, with theorists and planners condemning its inhumane planning practices and 'dull' aesthetic. Design was no longer considered an exercise in instilling strict rational organization, but rather a complex evolutionary activity. The functionally oriented, formalized geometries of modernism were supplanted by a diverse array of expressive technique. Led by a select group of avant-garde architects including Michael Graves, Philip Johnson and James Stirling, the post-modernist style founded its stylistic principles on a rediscovery of ornament and referential symbolism.

Post-Modern architectural theorist, Charles Jencks, refers to the mid-1970's demolition of Pruitt Igoe – a massive modernist housing development in St. Louis, Missouri, as the "day in which modernism died". (Jencks, 1977) The destruction of one of modernism's rapidly deteriorating developments ushered in a new age of architectural expression that re-birthed referential symbolism. The post-modernist style embraced classical geometries and re-established the role of ornament that modernism had so vehemently criticized. A pioneering post-modernist, Robert Venturi in his "Complexity and Contradiction in Architecture" (1977) advocated for an approach to understanding architectural composition and complexity, and the resulting richness and interest invoked by the embodiment of iconography in architectural expression. Complexity continues to be a common thread of discussion in architectural discourse of today. Post-modernism condemned the modernist notions of Utopian rationalism.

Post-modernism emerged from the 1970s avant-garde into mainstream discourse in the 1980s. By the late 1980s however, the post-modernist fascination with complexity combined with increasingly powerful, widely accessible computer hardware offered fertile ground for a new avant-garde to emerge – a successive paradigm building on the abstract ideals of post-modernism, only activated by computer technology.

Digital Expression

With the complex technologies, materials and communication systems available today, architectural expression in the digital era is rapidly evolving and expanding into previously unexplored formal territories. For the last two decades, designers have been concerned with the use of computational tools for the exploration of formal systems. These practices have greatly widened the field of possible forms. Consequentially, the calculative potential of the computer has rendered 'Rational Form' no longer synonymous with Euclidean geometry.

Today's globalized economy and unprecedented speed of information transfer has created an architectural language relatively unbound be regional typologies. As this digital epoch has arisen through the application of discrete computational techniques, the current formal language has become a disparate archipelago of geometries disconnected from any unifying framework. (Shelden & Witt, 2011)

Computational design has provided the ability to abolish preconceived notions of form toward the creation of unique geometries. With digital technology, architecture has transcended the common and predictable. (Shelden and Witt, 2011) Here, transcendency can be considered, "the quality of lying beyond the ordinary range of perception – the quality of lying beyond in response to timelessness and spacelessness". (Terzidis, 2003) One could argue that industrialization also offered a degree of transcendence – machinery and automation allowed the designer and craftsman to exceed physical capabilities of the human being, thus greatly restructuring global society. Similarly, computational design tools now afford the opportunity for the designer to exceed his or her own intellect. Generative modeling techniques can extrapolate patterns, interpolate complex curves and compute sophisticated algorithms into infinity. For the first time in the history of architectural discourse, the tool is no longer merely a means of production and representation, but rather a beholder of formal possibilities that lay beyond the cognitive means of the designer.

With these powerful computational tools at the architect's disposal, the digital paradigm has laid ground for a diminishing shape economy. Traditionally, some shapes take longer to rationalize and draw than others, dictated by the analog drawing instruments of the time. (Terzidis, 2003) However, computational strategies have depleted the time and effort required to develop complex formal systems. Coupled with quickly advancing digital fabrication tools, computational design provides the means to create and iterate non-uniform shapes with a similar degree of effort as that required for traditional Euclidean forms. This has expanded the realm of economically and structurally viable forms into a seemingly infinite swath of possibility. The result is a broad global collection of projects void of any rigid stylistic framework. The unifying principles of digital expression instead exist at an abstract level, celebrating complexity, dynamism and variation.

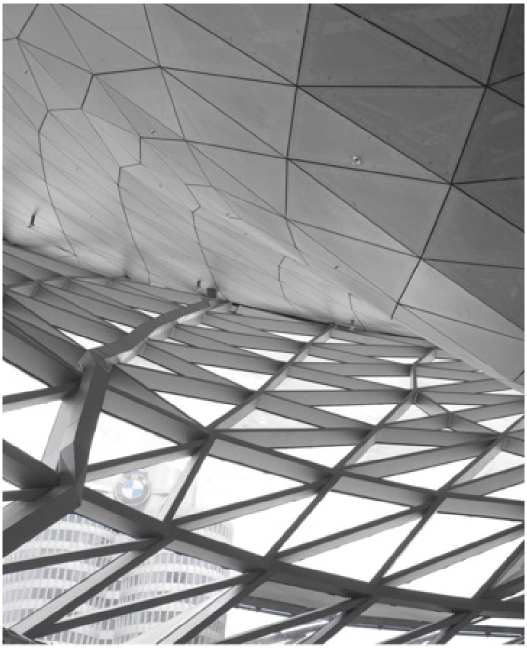
Figure 09 [Left]
Faceted cladding panels of the BMW Welt building by Coop Himmelb[l]au

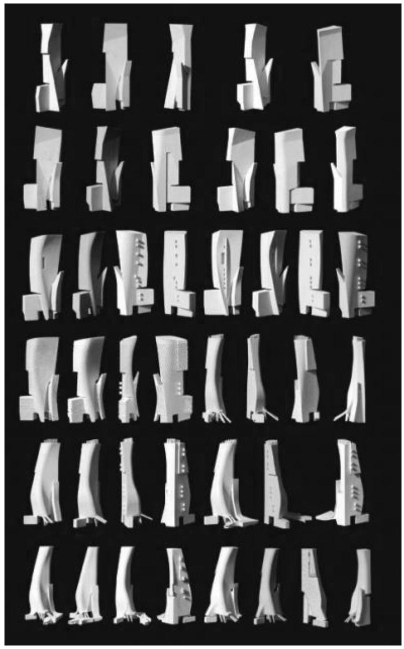
Figure 10 [Right]
Digital massing iterations of the Morphosis Architects' Phare Tower proposal

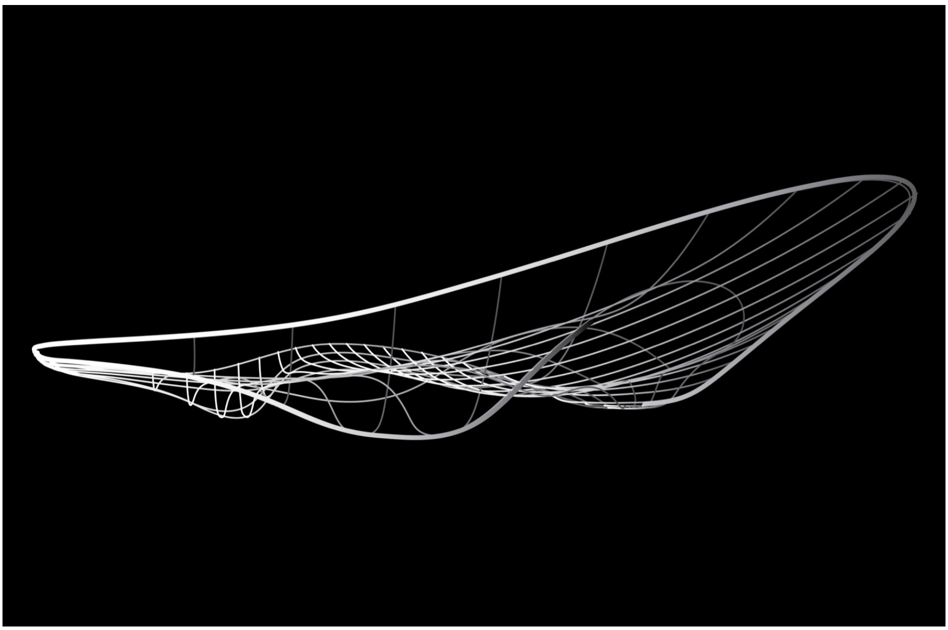
Similar to Ruskin's pre-modern theories around aesthetics and the Gothic style, variation is deeply entrenched within the formal language of digital architecture. The symbolic imitation of Classicism no longer holds connotative value and the rational, repetitive aesthetic of modernism is mundane and monotonous. Variation and its ensuing complexity is celebrated and spectacle is generated from innovation; creating the unexpected is a critical driver to digital expression. Not only does variation exist at a macro, discipline-wide level, but also at the micro level within the formal gestures unique to each project. Architecture of the digital age is no longer bound to the mere tessellation of identical modules – it is characterized by irregular forms achieved through a series of topologically identical, yet typologically unique components enabled by the computational tools available today.

For the first time, expression is derived neither from arbitrary creativity or technological determinism, but with creative computation and computational creativity. The harmonization of these two dialectically opposed strategies – arbitrariness and determinism - is a mode of expression dependent on digital experimentation and human interpretation. In the digital era, expressive form is the result of a synergy between the creator and the viewer, for without one another "expressive" or "form" cannot exist (Terzidis, 2003) The digital architect therefore has assumed the position of mediator between generative computational schemes and qualitative design decisions.

Figure 11
Roof Geometry of the London Olympic Aquatic Centre by Zaha Hadid Architects







Conclusions

While architects and theorists alike continue to add to a broadening collection of architectural 'isms' -classicism, modernism, minimalism, post-modernism, structuralism, deconstructivism and now parametricism to name a few – it is impossible to classify a style in which one currently operates. Virtually all stylistic theory therefore can be categorized in one of two approaches; the reevaluation of past theories and practices in pursuit of discovering parallel or recurring themes, or a search for new themes derived from concepts and industries foreign to architectural discourse. Style and expression must then be considered an evolutionary concept dictated by a complex network of contextual factors surrounding a particular epoch.

The central role Christianity played in renaissance Europe influenced Alberti to publish his Ten Books on Architecture. The rise of empirical understanding in the enlightenment era led Ruskin to develop his seven lamps. Corbusier drew from the potentials of advanced manufacturing tools and processes in the conception of his *New Architecture*. The rise of today's digital epoch however, cannot yet be attributed to a single event, publication or theorist. It is rather a rapid evolution of digital tools that have enabled and continue to reshape the architectural expression of today. The computer has become the agent of change, creating an architectural landscape void of traditional expressive principles. Digital design tools, while in many ways have homogenized the global architectural landscape, have also liberated designers from the status quo. While there certainly exists a common thread of design ideation, designers are now exploiting digital technologies to push the boundaries of what could never before been possible. Perhaps, for the first time in history, a style of an era can be characterized by its lack of a unifying framework and not by an overarching manifesto for expressive correctness.

02 | Computational Context

One could argue that no other technology has ever so rapidly reshaped civilization than the computer. Over the last half century, a relentless technological arms race has captivated global society, developing an insatiable appetite for digital innovation. Electronics manufacturers and network communications companies are posting record profits, while releasing smaller, faster, cheaper and more advanced products year after year. In a time where computer technology is so deeply embedded in culture, the term computer no longer carries explicit meaning. The 'computer' has evolved to become an ambiguous techno-cultural construct, vaguely applied to a wide array of devices surrounding all aspects of contemporary life.

To limit the term's application solely to the electronic devices of recent decades would be misleading. The computer was a cultural invention before technological. (Wurster, 2001) Regardless of its overt connotation with the graphic user interface, the 'computer' is not a contemporary notion. The term - from Latin, *Computare*, to calculate - was first recorded being used by Sir Thomas Browne in 1646, referring to someone who performed calculations required for drawing a calendar. (Schumacher, 2011) It retained this meaning until the early twentieth century: a mathematical occupation where one performs calculations with the aid of tables, had the title "the computer". The computer therefore, since its extreme infancy has always performed the specific task of processing complex numeric equations.

From the time of Vitruvian geometric ideals to Corbusier's modular and the complex NURBS surfaces of today, architecture has always been bound to (if not by) a conscious use of numbers. In this light, it is no surprise that the computer is so entrenched in architectural discourse of the last half century. The technology offers a potent medium for the exploration of formal organizational structures, the storing of data and the automation of redundant tasks. All facets of the architectural discipline have experienced an evolution in close parallel with that of the computer.

The Computer

It is nearly impossible to definitively locate the starting point in the history of the computer. Firstly, there are several different definitions of the term and secondly, innovation is cumulative; the contributions of many individuals have come together in the course of its development. In their text Künstliche Intelligenz: Philosophische Probleme (Artifical Intelligence: Philosophical Problems), Walther Zimmerli and Stefan Wolf argue that three parallel threads of preceding intellectual and technological developments led to the creation of the modern computer; formalization, mathematization and mechanization. (Wurster, 2001)

Formalization describes the creation of a philosophical approach to developing a logic; a conceptual sequence of interrelated actions toward the creation of an output from a particular input. The computer as a “universal machine” required a universal language – a means by which humans communicate with the hardware to perform a variety of functions. Mathematization however, refers to the calculation of quantitative values. Closely interlinked with formalization, mathematization refers to any system for obtaining particular figures from other figures by applying a particular set of rules. With the rise of empirical intelligence during the 19th century, mathematics came into new-found relevance in chemistry, physics and biology, contributing to the foundations of modern computational theory. Mechanization, on the other hand, is technologically based and refers to the replacement or magnification of muscle power by mechanical power. On the heels of the industrial revolution, mechanization became a prominent topic of discussion, inspiring scientists, engineers and mathematicians to explore potentials of the new technology.

Computers, in their most primitive form, first emerged in the mid-17th century. Some of the earliest notable computers were the ‘calculating machine’, the product of mathematician and astronomer Wiilhelm Schickard 1623, the ‘Pascaline’ by Blaise Pascal in 1642 and the ‘stepped cylinder’ in 1673 invented by Gottfried Wilhelm Liebniz. (Wurster, 2001) Liebniz plays a prominent role in the history of mathematics to present day, as he is widely regarded as one of the most prolific inventors of mechanical calculators. Leibniz is also responsible for the refinement of binary notation, a computational language still employed in mathematics and digital electronics over 350 years later. These early forms of the ‘computer’, however only performed one function, or a very limited range of similar operations. These mechanisms lacked the ability to perform different tasks based on programmable inputs. The logic of the calculating machine was rigid and unadaptable.

Like all tools prior, the computer was intended to increase convenience and ultimately expand man’s physical and mental capacity. However, where the computer strays from traditional tools is in its ability to carry out not just one task, but a wide array of functions. Unlike most tools, it is not designed for just one purpose or a few related purposes, but is a machine that, in Alan Turing’s words, “is capable of simulating any other machine” (Wurster, 2001) In 1745, French inventor and artist, Jaques de Vaucason conceptualized the first “programmable” computer with the invention of punch-card technology. Decades later, Joseph-Marie Jacquard used this primitive form of machine language to refine the automatic loom to create complex weaving patterns based on data inputs from a refined version of Vaucason’s perforated films. Thirty years following Jaquard’s loom, English inventor Charles Babbage adapted the same punch card technology for incorporation into a calculation machine – dubbed the “analytical engine”. This format of data transfer is widely considered to be the very first binary language – instead of ones and zeros, as with binary notation, the punch card employed a series of solids and voids. This method is the earliest example of a machine language – a codified data input capable of producing infinite outputs.

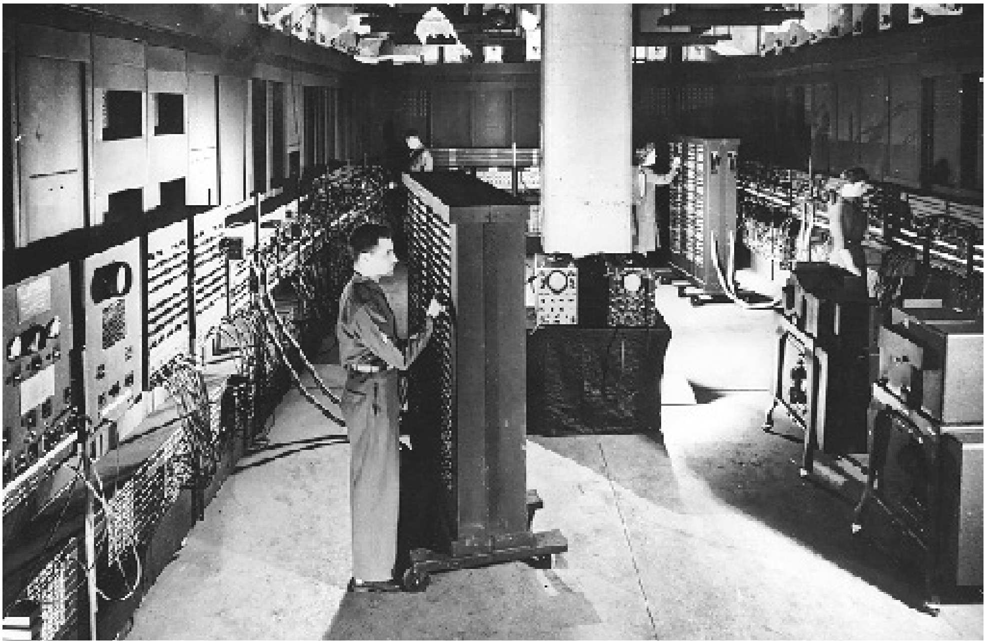
First emerging in the 1930s, the electronic computer, like many other technological innovations past, gained relevance in its potential to benefit military operations. In 1934, German civil engineer Konrad Zuse, begun the design of a calculating machine, eventually refining his series of unreliable primitive prototypes into a the Z4 in 1941 – the world's first programmable electronic computer. Shortly thereafter, the Harvard Mark I, a massive 'automatic sequence controlled calculator', was developed in the United States, becoming the first ever computer in North America. (Wurster, 2001) By 1945, the American government recognized the opportunities of computer technology and commissioned a new digital computer to be built, eventually to be named the Electronic Numerical Integrator and Calculator or 'ENIAC', which was eventually employed by the American government to optimize configurations for overseas bombing missions. These advancements in electronic computer technology signaled the beginning of massive societal interest and rapid acceleration of computer development for the next half century.

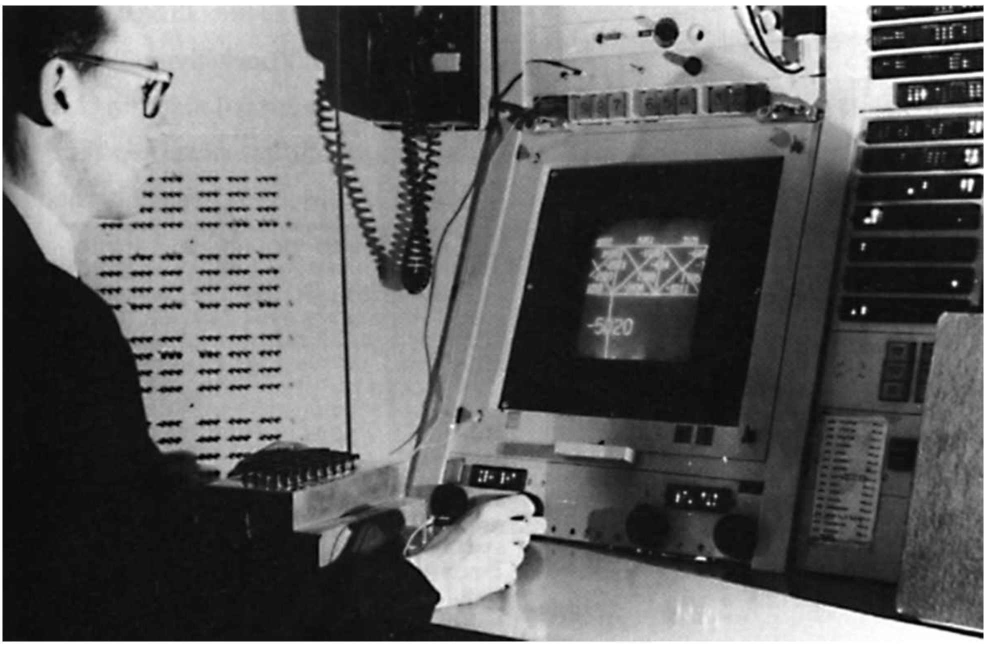
Figure 12
Inventors Mauchly and Eckert operating the ENIAC (Electronic Numerical Integrator and Computer)

The first consumer vacuum tube computer was developed by IBM in 1952. Named the 'Model 701', the tailor-made machine was aimed at the goal of enhancing efficiency and capability for businesses and corporations. For the ensuing three decades, IBM occupied a central role in the continuing development of computer technology. With enormous technological advancements in the 1960s, techno-culture across the globe experienced rapid growth to the point where the complexity of integrated circuits doubled every two years. (Wurster, 2001) These advancements in micro-technology began to shift the perception of the computer from a massive mainframe to a compact device employed in laboratories, offices and factories capable of executing various tasks by a single user.

In 1971, Intel developed the first ever microprocessor, ushering in a new era and forever changing the landscape of computing. The microprocessor enabled the development of the personal computer, because of its small size and unprecedented affordability. An arms race ensued as a broadening industry of computer manufacturing companies continued to successively evolve the microprocessor and its corresponding graphic interface. This rapid development eventually gave way to the emergence of the personal computer. In 1976, Steve Wozniak and Steve Jobs completed their Apple I – the first true personal computer followed by the even more successful Apple II a year later, which featured 'open architecture' allowing third party companies to develop additional plug-ins to extend the machine's functionality. The

Figure 13
Ivan Sutherland demonstrates the 'Sketchpad' graphic user interface

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Apple II was therefore the first computer to truly embody Turing's vision of a universal machine. Here, the program software (literally a plug-in) evolved to become just as critical a component as the hardware itself. Building off the Alto graphic user interface (GUI) developed in the 1970's by Xerox Corporation, the Macintosh's operating system (Mac OS) released nearly ten years after the Apple I made the computer accessible to the general public. In an affordable, compact, user friendly package, Apple brought computational power to the masses (Wurster, 2001). As software, operating systems, GUI's and internal hardware continued to evolve, industries, companies and individuals began to appropriate the technology to their unique demands. Laboratories, offices, factories and a myriad of other applications began to incorporate the computer into their work-flow in the name of efficiency and growth.

Over the next three decades into current day, Apple, alongside Microsoft, still holds a dominant position in a drastically changed computer market. Today, the computer is no longer limited to a desktop device – laptops, tablets and mobile phones are all now universal machines both in their widespread accessibility and their functional capability. The number of cellphones in the world is now equal to the number of people. Between one and two billion more people in the world have a cellphone than a toilet. Global smartphone sales alone reached one billion units in 2013, making the internet enabled mobile device the fastest adopted technology ever. (Evans, 2014, 17-36)

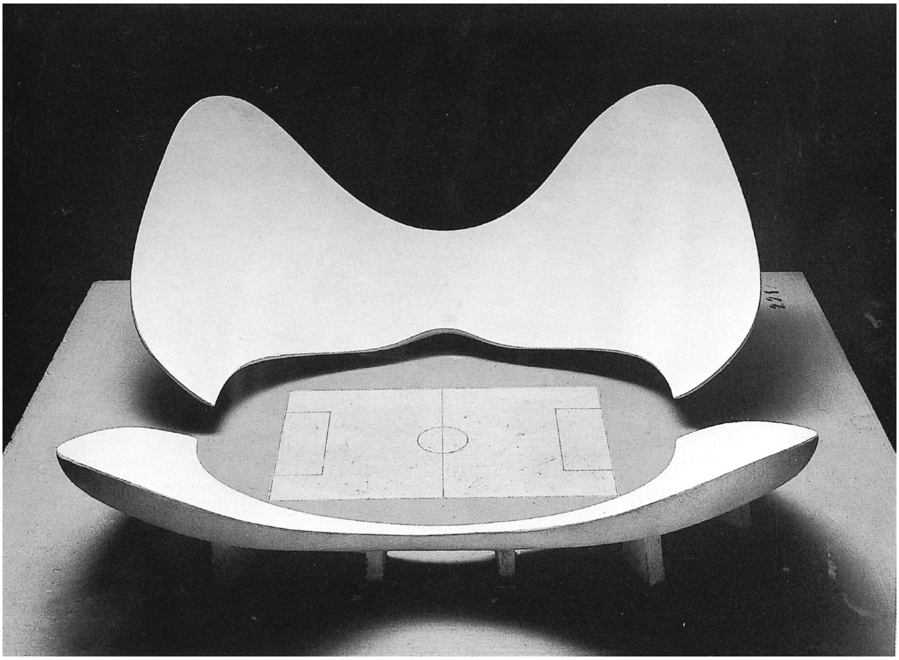
From the primitive calculation machines of the 17th century, to the microscopic all-encompassing hardware of today, the computer remains a potent tool for the further advancement and innovation in virtually every discipline. The result of centuries of cumulative innovation – Liebniz's binary system, Vaucason's punch card, Zuse's programmable machines, von Neumann's architecture, Intel's microprocessor and Apple's personal desktop – have all contributed to the development of the tools at society's disposal today.

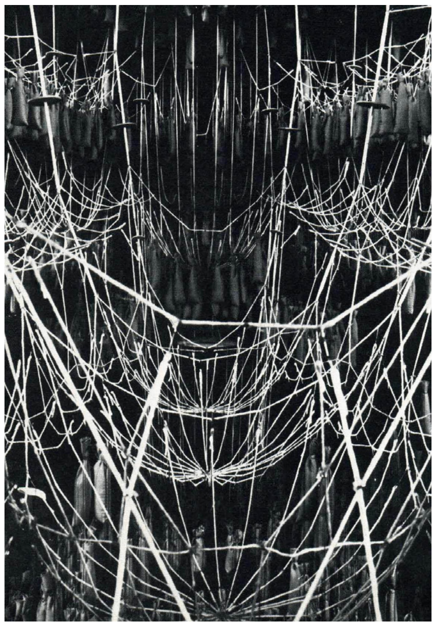
Architectural Computing

The digital environment made possible by the computer has unveiled new potential in both scientific and creative pursuits offering, perhaps for the first time ever, the potential to expand human intellect. Architectural discourse of today has fully appropriated the technology, making the computer a critical tool in the role of the contemporary architect. It would be near impossible to find an architectural design office functioning completely analog today. Architectural computing however is not limited to the common methods in mainstream practice today such as, AutoCAD and building information modeling tools. Pioneering examples of architectural computation first emerged long before the advent of the personal computer.

The computer, in the broad definition of the term first permeated architectural discourse in the 1930s, at a time where Turing, Zuse and Neumann were laying the foundational framework for the modern computer. Similar to the calculation machines of Schickard, Pascal and Liebniz, architects begun to devise experimental models and devices to conceptualize, evaluate and iterate complex data and geometry.

Antoni Gaudi, known most prominently for his organically inspired, mathematically precise forms, employed analytical models – primitive computational devices - to rationalize, visualize and refine the complex geometry of his projects. Gaudí's thorough comprehension of mathematics is rooted throughout his architecture, almost entirely comprised of mathematically ruled surfaces – helicoids, paraboloids, and hyperboloids - each mutually interdependent through a primitive parametric logic built of ruled lines, booleans, ratios, and catenary arches (Mark Burry and Jane Burry, 2010) To derive these doubly-curved forms, Gaudi essentially created a series of analog calculation devices – form-finding chain models. Hundreds of meticulously configured weights and cords were assembled and suspended to create an inverted model of the desired geometry. Exploiting Hooke's law of spring behaviour, Gaudi was able to manually compute the shape of catenary curves through the force of gravity on weighted strings.





The hanging chain model can thus be considered a primary example of an analog parametric design tool. Gaudi's device employed a series of independent parameters - cord length, anchor location and weight - each easily manipulated and acting in correlation toward the realization of an infinite amount of outputs. The internal logic of the system therefore produced the location of points along each cord. The parametric equation here was basically Newton's law of motion. The hanging chain model enables formal exploration by limiting Gaudi solely to structurally sound geometries while generating optimal curvature with every manipulation of the model's parameters. (Kolarevic, 2008)

Frei Otto, another 20th century architect widely reputed for his experimentations with analog parametric models, referred to this design process as form-finding. Otto experimented with hanging chain models and further contributed to analog computing with soap films and minimal paths derived through saturated strands of wool. (Kolarevic, 2008) The German structuralist, like Gaudi, managed to determine mathematical relationships governing natural phenomenon and successfully applied this foundational logic to his full-scale work. This mode of operation begins to demonstrate the complications, benefits and alternative methods of thinking associated with parametric design. These analog 'computers' allowed the designer freedom to explore varying outcomes each equally true to their governing principles, imparting qualitative and tacit knowledge throughout the evaluative process to arrive at an optimal result.

Figure 14
Physical model of Luigi Moretti's parametrically devised Stadium N Proposal

One of the first architects to explicitly discuss "parametric architecture" was Luigi Moretti. The Italian architect defined parametric architecture as, "the study of architecture systems with the goal of defining the relationships between the dimensions dependent upon the various parameters". (Davis, 2014) Moretti devised a design scheme for his Stadium N proposal to explain how a form could be derived and manipulated based on a series of design parameters. Sight lines, material costs and shell curvature were a few of Moretti's 19 foundational considerations for the stadium's logic. This parametric approach to optimization is only different from that of Gaudi and Otto's analog models, in that Moretti transcended the laws of nature as the parametric equation. The Stadium N proposal rather considered performance in the satisfaction of a variety of functions, both quantitatively and qualitatively evaluated.

Figure 15 [Left]
Frei Otto's Experimentation with minimal paths with threads dipped in Syrup

Figure 16 [Right]
Antoni Gaudi's hanging chain geometric model for the chapel of La Sagrada Familia

Whereas Moretti functioned in an analog method of parametric design thinking, the advent of the personal computer offered architecture a new medium in which to formulate, visualize and iterate logic. The computer made incalculable complexity rational and therefore possible. Computation effectively veiled the complex mathematic processes of parametric design behind a graphic user interface – the modern calculation machine continued to perform its primitive function - the calculation of complex equations. In the late 1980s, architects began to take note of the potentials that design computing could afford in the process of form finding and representation.

Digital technologies first permeated architectural discourse largely in two fundamental streams of thought, both of which utilizing the computer as a visualization tool. The first - a select group of avant-garde designers begun to explore the potentials of the computer in scripting to develop unique tools tailored to their intentions. Conversely, the introduction and widespread adoption of AutoCAD instigated a major shift in mainstream practice where the computer was adopted merely as a drawing tool.

In the early 1990s, the emergence of digital tectonics occurred in parallel with the development of spline modeling – new software that became much more accessible due to the availability of cheap processing power. (Eisenman, 2013) A small cohort of architects and designers begun to explore the potential of using the computer to create complex customized visualization tools that allowed the manipulation of geometries on a screen, employing graphic notations like vectors and control points. (Eisenman, 2013) Architects such as Chuck Hoberman, Frank Gehry and Peter Eisenman became leading proponents of early digital architecture – looking to the computer as a new virtual medium in which to create, evaluate and iterate their experimental models. The hanging chain models and soap bubble studies were now digitized, existing in a virtual environment, unbound by natural laws and material behaviour. These designers worked closely with computer scientists and software engineers to develop customized digital platforms for form finding and exploration of previously unimaginable and incalculable formal geometries.

Peter Eisenman expanded upon digital parametric design an architectural context, conceptualizing an abstract diagram for the description of a building and developing a diagrammatic 'DNA structure' toward establishing an organizational logic of a building.

Figure 17
Peter Eisenman's abstract sketch of a codified building 'DNA'

Eisenman approached the computer department at Ohio State University – where he was working at the time, and sought to produce iterations of a digital DNA sequence to create a diagrammatic plan of a building. (Lynn, 2003) Abstracted logic was exchanged between his office and the university, each time redrawn and iterated in a search for a deep organizational structure. At a time where design computing was in its relative infancy, Eisenman was exploring a new digital language to describing architecture, developing a potent theory of parametric design nearly two decades prior to its appropriation into mainstream architectural discourse.

While the digital innovations of the 1980s and 1990s were profound in their impact on practice, computer aided drafting and visualization fundamentally did not alter the traditional role of the architect. Marshal McCluhan, media theorist and author of the Medium is the Message, makes note that when a new technology is first introduced, it first aims to replicate what it is replacing. (McCluhan and Zingrone, 1997) Digital tools in architectural practice were no exception to this phenomenon. With the advent of AutoCAD in mainstream practice, architects employed the computer merely as a new means of producing the same thing they have for centuries; orthographic projections diagramming the composition and assembly of a final product. Computer aided drafting enabled rapid iteration and the automation of mundane tasks, however did not immediately reshape design thinking.

Design computing expanded in scope beyond representation-based documentation to include analysis, simulation and digital fabrication. As the automotive and aerospace industries began to develop and adopt software capable of producing integrated data models, cutting edge architects began to explore their application to the design of buildings and their components. Building information modeling emerged as the first wave of digital evolution with architects like Frank Gehry and Zaha Hadid beginning to integrate engineering and fabrication software like

CATIA into their design processes to economize the handling of project data and achieve truly unique geometries both in visualization and construction. The digital artifact was no longer a planar representation of the building, but rather a virtual prototype. Contemporary theorists, Sanford Kwinter and Manuel DeLanda have both highlighted this shift, made possible by information models, whereby the previous method of architectural delivery - the 'possible to real' - is being supplanted by a new and seamless one - the 'virtual to actual'. (Garber, 2009). With building information modeling, for the first time since Alberti's codification of architectural drawing in the renaissance, architects begun to produce a truly new medium. (Scheer, 2014, 13) The integrated model became a sophisticated parametric system, allowing the architect to modify physical parameters of material, form and scale in addition to an underlying collection of data – 'effectivities' – capable of storing time-based information for operations like fabrication, assembly and post-occupancy performance.

While building information modeling, like AutoCAD of the early 1990's, is the dominant mode of architectural computing in the last five years, parametric free-form modeling has also evolved significantly since Eisenman's experimentations with building 'DNA'. A re-invigorated interest in geometric complexity and widespread digital literacy amongst a new generation of architects has combined with powerful hardware and proprietary software, creating a widening swath of designers developing their own parametric platforms and notations. C#, Processing, Python, VBScript, RhinoScript and Grasshopper are all graphic interfaces employed by designers to develop a custom parametric logic – proverbial digital 'calculation machines'. These designers are finding expression from within the process of making as a new species of architecture, bringing mathematics into new-found relevance while engaging in dialogue with the computer in a mutually informative relationship.

Parametricism

In today's paradigm, the computer's role in architectural design can be categorized into three prevailing strategies; representational, algorithmic and parametric. (Kotnik, 2010) Representational strategies regard the computer primarily as an electronic drawing tool. AutoCAD is still a prevalent tool in the contemporary architect's arsenal and building information models are still often cut and diagrammed in two dimensional drawings generated from a virtual prototype. The computer enables a geometric language that could not otherwise be controlled easily through manual means. Representational computing is still in line with the visual reasoning of the traditional paper-based approach.

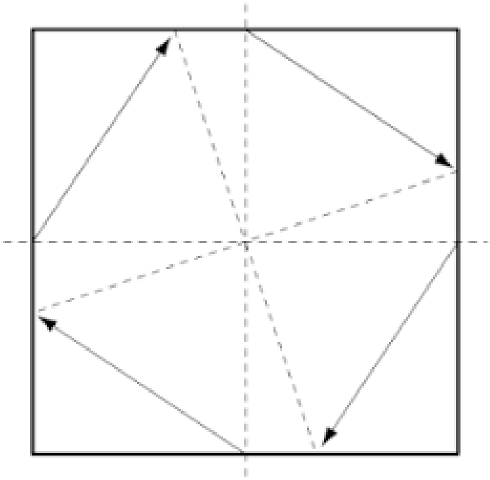
Figure 18 [Left]
Diagram of Ito and Balmond's successive 1/3 rotational subdivisions for the 2002 Serpentine Pavilion

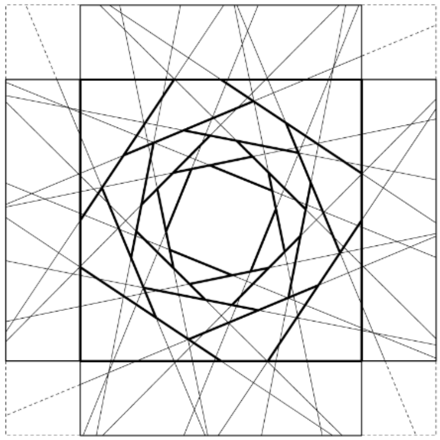
Figure 19 [Right]
Resultant algorithmic facade subdivisions of the 2002 Serpentine Pavilion

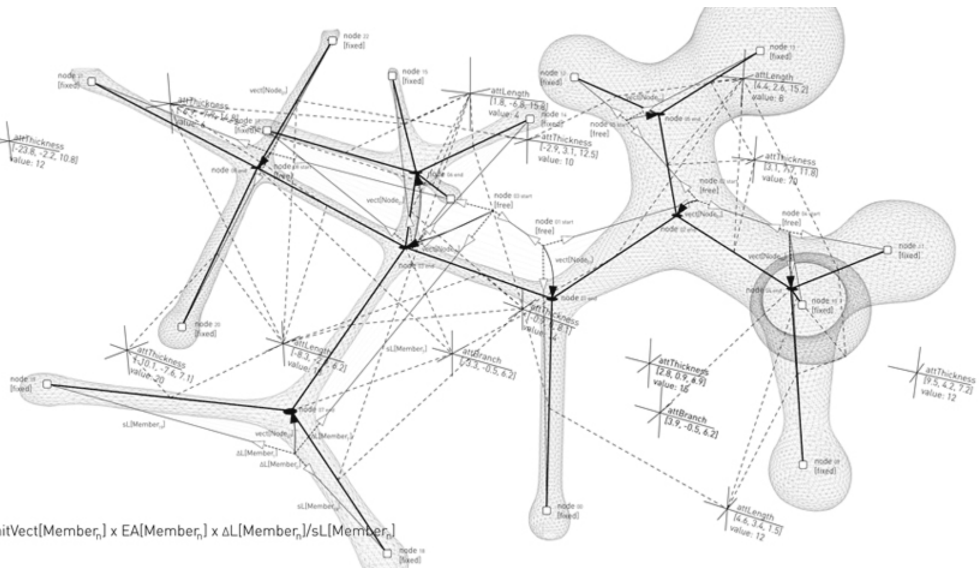
Algorithmic strategies however are founded upon a fixed relationship – a focused mathematic equation generating variable outputs from a quantifiable input. Toyo Ito and Cecil Balmond's Serpentine Gallery pavilion in 2002 is a primary example of an algorithmic design approach. The structure features a successive subdivision of its facade, creating a field of varying porosity and density defining structural organization and glazing distribution. The scale, location and rotation of intersecting planes is dictated by an algebraic operation. In algorithmic strategies, the focus is on the development of logic that is a sequence of mathematic, analytic and geometric operations for the manipulation of data and its translation into architectural properties. (Kotnik, 2010)

The third level of computation – the parametric, shares many of the same characteristics of the algorithmic approach. Where this strategy differs is that the logic does not consist of a single algebraic equation, but a devised network of causal relationships between quantified design considerations or parameters. In addition, where algorithmic strategies are generative in that the final output is unknown until an input value is assigned, parametric design requires a clear understanding of the computational relationship and its integration into the design process as an interdependent element amongst other design components.

Figure 20
Algorithmic relationship diagram generated for the 'Protosynthesis' project by David Pigram, Iain Maxwell







$$vect[Node_a] = \int_0^n unitVect[Member_n] \times EA[Member_n] \times \Delta L[Member_n]/sL[Member_n]$$

In a parametric approach, it is the considerations of the designer's intent that are declared and rationalized, not the formal composition. As opposed to describing the final product as a physical manifestation (such is the case in representational approaches), the logic of modeling itself is described. (Scheurer and Stehling, 2010). Rather than developing a traditional parti, the designer constructs a formal system, controls its behavior through digital manipulation, and selects forms that emerge from its operation for further development. There is nothing automatic or deterministic in the definition of actions and reactions: they implicitly create "fields of indetermination" from which unexpected and genuinely new forms might emerge. (Kolarevic, 2003)

This logic (factor 'F'), is perhaps the most revolutionizing factor of the parametric design process. Bernard Cache refers to this logic as the 'objectile' describing the term as, "an open ended notation which allows for infinite parametric variations". (Perella, 2013) Derived from Gilles Deleuze's "Topologizing of Architecture", the objectile is a guiding framework activated with the assignment of input values, creating a series of topologically identical, yet typologically unique outputs.

Take for example, the topology of the human body. All humans share the commonalities of a body plan – two eyes, one head, ten fingers – yet each one of the seven billion humans on earth is a unique amalgam of genetic parameters. It is clear that the kind of spatial structure defining a body plan cannot be metric, since embryological operations can produce a large variety of body types, each with a unique metric structure. (DeLanda, 2002) The genetic code of DNA therefore can be considered an extremely complex, naturally occurring objectile. It is only when values are assigned to this logic – colour, texture, size and so on, that the typological object - the body - is formed. Peter Eisenman, with his building DNA experiments in the early 1990s, clearly made this salient connection. His iterated diagrams are an early

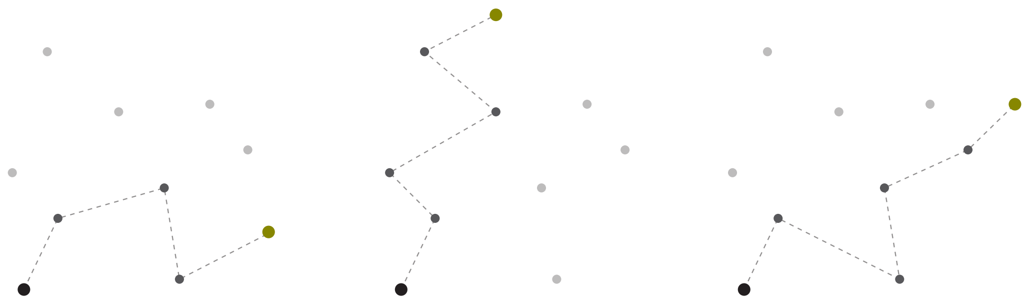


Figure 21
The Traveling Salesman Dilemma: Traversing Fields of Indetermination

architectural equivalent to DNA's diagrammatic double helix. Therefore parametric architectural strategies strive to achieve the same degree of combinational productivity as biological systems by developing critical connectivities in the design process.

The structure of this network of interdependencies is dictated by the designer's ability to qualify rationalize and distill all contextual forces into an efficient organizational framework concise enough to arrive at the final solution, while allowing for the maximum degree of design variants. Building a parametric model means reducing the infinite complexity of the real world to a level where it can be described with manageable effort. (Scheurer and Stehling, 2010) A perfect model does not contain as much information as possible, but as little as necessary to describe the properties of an object unambiguously. Scheurer refers to this design dilemma as the 'traveling salesman problem', where one must determine the most efficient, optimal route of travel - a sequence of geometric operations - between given cities on a list - a collection of considerable parameters. (Scheurer and Stehling, 2010) The designer must eliminate all superficial considerations, thus requiring a considerable degree of qualitative intelligence because it involves finding patterns and defining general cases.

In a parametric approach, the work of the designer has therefore shifted to a higher level of abstraction. The difficulty of devising a parametric model is to untangle the interdependencies of all requirements to discover a series of principles that are as simple as possible, yet flexible enough to accommodate every occurring case. In other words: to pinpoint the view to the exact level of abstraction where no important point is lost and no one gets distracted by unnecessary detail. (Scheurer and Stehling, 2010) In this approach, conceptual emphasis shifts away from particular forms of expression (geometry) to relations (topology) that exist within the context of the project.

Conclusions

The permeation of computational methods into architectural design has opened up a path along which mathematical methods of investigation from fields like topology, differential geometry, or complexity theory can diffuse into architecture. (Kotnik, 2010) The computer is now an applied calculation machine that allows designers to navigate complex algebraic relationships toward the realization of form. With the ability to digitize Gaudi's hanging chain model's or Otto's soap film experiments, architects can explore concepts like continuity and smoothness, differentiation or self-organization through the visualization and automated processing of mathematical functions.

The computers of today still perform the same basic function as Schickard, Pascal or Liebniz's automated calculators of the 17th century. The technology performs hidden mathematic processes behind the veil of a graphic user interface, enabling the untrained user to perform high level calculations that previously laid beyond their individual intellectual and creative capacity.

As computational tools continue to evolve, architectural discourse promises to expand into previously tangential realms of inquiry, discovering new relationships facilitated by digital design processes. As a result, digital fabrication, immersive environments, responsive systems and material computation have emerged as prevalent topics in current architectural praxis. Architects and designers continue to stretch the capabilities of the computer toward new design outcomes driven by parametric processes. This new found affinity for creative computation has had a profound impact on the nature of architectural ideation and architectural culture. Whereas architects have traditionally repressed innovation to preserve relevance in such a vulnerable, economically driven industry, the computer has transformed the architect into a digital creator – a mediator between context and computer.

03 | The Current Paradigm

As with virtually every facet of contemporary society, computing is deeply entrenched in the culture of architectural discourse today. With complex software and the rapidly developing hardware, architects now possess a myriad of digital tools at their disposal. While computers are not the designers of buildings, software protocols and limitations certainly have had profound affects the direction of design culture. (Holden, 2012) Understanding the technology of computing is just as important as understanding the technology of construction in allowing architects to design and manage complex projects. The architect of the current paradigm has become a digital craftsman - negotiating a wide array of digital tools while understanding the limitations and opportunities that each affords.

Contemporary practice is characterized by a willingness to explore the architectural applications of emerging technologies and means of production. In addition to digital form-finding tools, the internet and related communication technologies have also revolutionized the architectural landscape. With the unprecedented speed of communication today, practices of varying scales can assume a broader range of identities than ever before. In this context, overlap among practices, disciplines and technology has become the status-quo. It is not uncommon for multiple offices to work in tandem on a single project, each imparting their own specialized knowledge on the process. This technologically mediated network is a landscape of entangled scales and operations in which conventional notions of practice have been redefined.

In an environment dictated by economy and efficiency, mainstream practice has adopted digital tools as a means of design determination and justification. The architecture of a digital paradigm largely is void of symbolic forms or rigid criteria, instead emphasizing sustainability, innovation and complexity. The role of the parti has declined in favour of performative criteria. Louis Sullivan's iconic 'form follows function' has been supplanted by 'form follows performance' - a new found form of technological determinism enabled by the third wave.

Convergence

Today's architectural paradigm is centered on notions of convergence. Building information modeling is bridging the long divide between architect and builder. To practice digitally within an ever-expanding architectural field can take a wide array of formats. The profession has become more interdisciplinary, with the rise of research in information design, building simulation, parametric and computational form-finding, prototyping and fabrication to name a few sub-fields. (Hoxie, 2009) While these strands of inquiry are evolving into their own bodies of disciplinary knowledge, there is also a movement toward convergence – an attempt to use these topical streams in a vertically integrated way toward a sort of meta-digital practice.

Digital technology in architecture can be categorized into three fundamental directions only recently converging to become a single coherent system. (Marble, 2010) The first direction is in parametric design, where topological relationships are developed resulting in complex form, replacing geometry with a formal mathematic logic. Secondly, building information modeling has allowed for the management of vast amounts of information that can be deposited, linked and evaluated. Lastly, the development of digital fabrication technology is reestablishing the role of craft in architectural design, demanding a close working relationship between the architect and the tools, materials and processes responsible for fabricating their creations.

File-to-factory fabrication processes have demanded the architect work in close collaboration with material scientists and manufacturers toward the full-scale realization of architectural complexity. Clients have more control over design decisions and alterations, working closely with all stakeholders in an integrated design process. The boundaries of thinking and doing, design and fabrication, prototype and final design are now blurred, interactive, and part of a non-linear means of innovation. (Iwamoto, 2009) Traditional design processes

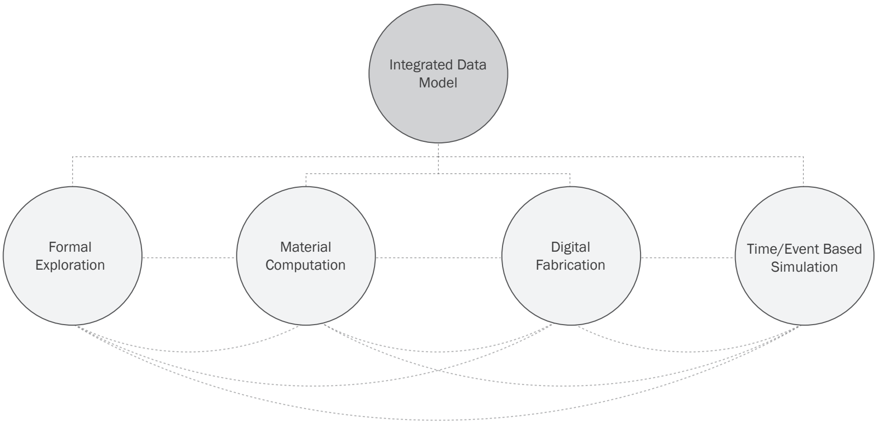


Figure 22
The integrated data model as a facilitator of converging modes of inquiry

are comprised of a work flow that can be distilled into two fundamental phases: representation - encompassing the visualization and illustration of a desired product, and interpretation - referring to an exchange of information intended on guiding its fabrication or assembly. Current digital design and fabrication technologies are capable of consolidating this work flow into a singular non-linear process; design information has become construction information.

Enabled by digital fabrication technology, file-to-factory processes have made understanding of material behaviour and manufacturing techniques critical to the design process. Lisa Iwamoto in “Digital Fabrications: Architectural and Material Techniques” (2009), mentions the new fundamental importance of material, tool and manufacturing processes in design;

> *This demands that architects essentially learn a new language. Some aspects of this translation are relatively automatic and involve using machine-specific software; others are very much in the purview of the design. Decisions as to which machine and method to use must marry design intent with machine capability. It has therefore become necessary for digitally savvy architects to understand how these tools work, what materials they are best suited for, and where in the tooling process the possibilities lie. (7)*

The architect of today’s paradigm therefore must have an inherent understanding of the materials and processes involved in the fabrication of the components they envision, whereas traditional methods of building procurement left these detailed considerations to the fabricator, manufacturer or sub-trade. The paradigmatic gap between design and construction is narrowing as computational design strategies are shifting the traditional role of both the architect and the builder.

Kas Oosterhuis, Architect, co-founder of ONL Studio and Director of the Hyperbody Institute at UT Delft advocates for a design thinking centered on the concept of convergence - what he refers to as "one building, one detail". (Oosterhuis, 2011) Drawing from the potentials of integrated data models and file-to-factory fabrication methods, Oosterhuis employs topological variation of a singular unitized component to realize his architecture. ONL's Acoustic Barrier project completed in 2004 in Utrecht, Netherlands, exemplifies Oosterhuis' design mentality centered on convergence. The building is modeled parametrically to enable the tessellation of steel armatures to negotiate the building's serpentine curvature. From the digital model, steel components were fabricated free of any human interference. ONL regards their 3D model as a perfect representation of the building avoiding the tendency for the building to be subjected to abstractions like drawings. (Oosterhuis, 2004) These computational design techniques have therefore instigated and reinforced a culture of convergence in recent architectural discourse.

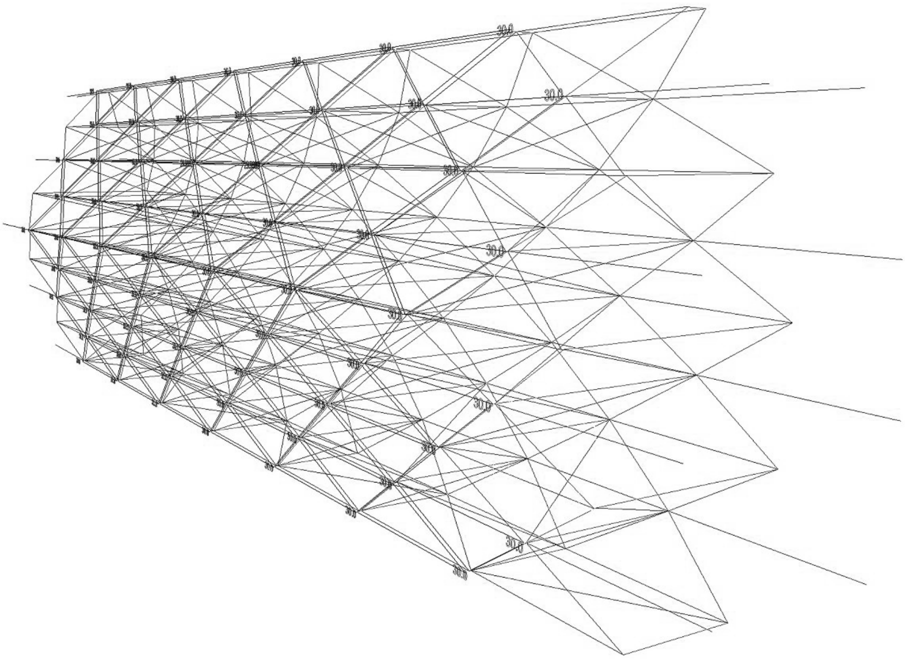
Figure 23
Cockpit in an Acoustic Barrier regulating lines of the integrated digital design-fabrication model

Today, an expanding swath of interdisciplinary practices have emerged, employing computational techniques to draw from previously tangential disciplines for the advancement of architectural design. Chris Hoxie, co-founder of MOLT Studios is a key proponent of this digital cross-pollination. The architect and professor of Immersive Environments in the digital design sequence at Harvard University centers his research on how techniques of rendering and animation and the simulation of digital content within the entertainment industry can expand the practice of architecture. (Hoxie, 2009) By borrowing methods from the entertainment industry, Hoxie is interested in expanding architectural practice by seeking out opportunities enabled by the technologies used in film production. In his essay, Convergence: Toward Digital Practice (2009), Hoxie explains, "we seek to fold in the design, construction, simulation and presentation of virtual constructs and their environments by recreating various physical phenomena." The virtual environment has enabled Hoxie and other designers to discover the potentials of tangentially related disciplines, contributing to a broadening landscape of architectural expression and form.

Echoing Chris Hoxie's fascination with film technology to develop virtual environments, at a macro level, the concept of simulation is a central point of theory and discussion in current practice. Architects have turned to digital tools originally developed in foreign industries as a means of formal exploration and management. Advanced software developed by interdisciplinary teams of building scientists, engineers, computer programmers and architects are driving the theme of convergence deeper into architectural culture.

Figure 24 [Right}
Cockpit in an Acoustic Barrier parametric detailing with an integrated digital design-fabrication model

Figure 25 [Left}
Cockpit in an Acoustic Barrier digitally fabricated steel armatures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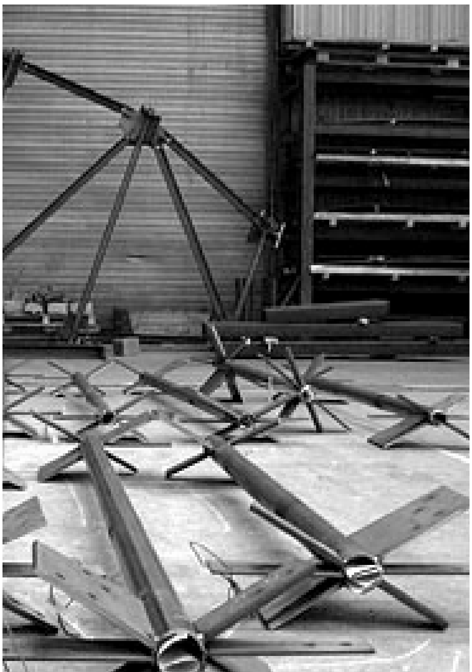
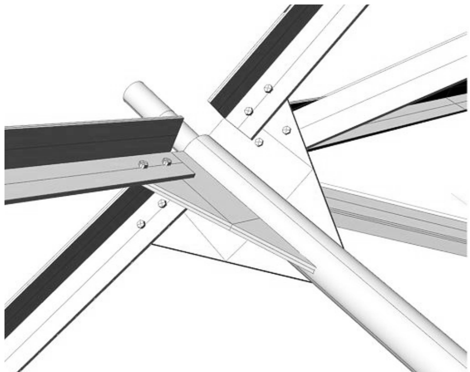
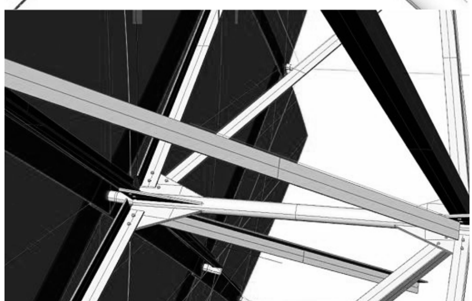


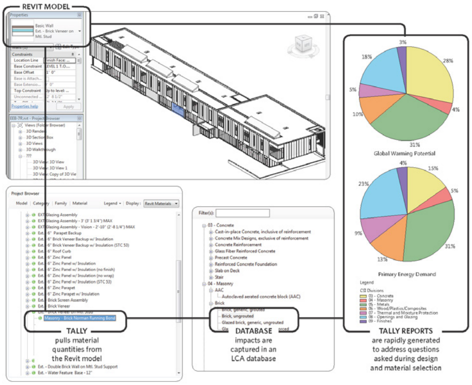




The Age of Simulation

Design computing has expanded in scope beyond representation-based documentation to now include analysis, simulation and digital fabrication. The divorce of design from construction, theorized by Alberti and realized in modern practice, is being overthrown by the replacement of drawing by simulation. Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviors of the selected physical or abstract system. Techniques of dimensional or geometric representation, formerly part of an abstract process of drawing, have evolved into an integrated system of design information embedded in production and assembly processes. (Marble, 2010) Architects are no longer limited to the fragmentary representation of physical ideas; they can now fully pre-form them. (Kieran and Timberlake, 2004) Simulation collapses the distance between representation and artifact, establishing instead a functional near-equivalence.

Building information modeling (BIM) – the most prominent trend of the last decade in architectural practice has played a large role in this shift toward simulation from drawing. According to the US National Institute of building sciences, BIM refers to “the use of the concepts and practices of open and inter-operable information exchanges, emerging technologies, new business structures and influencing the re-engineering of processes in ways that dramatically reduce multiple forms of waste in the building industry.” (Garber, 2009) With software applications like digital project, CATIA and Revit, architects are able to integrate data and engage in an iterative dialogue with a virtual prototype. A single, intelligent virtual model can be used to satisfy all aspects of the design process, including visualization, spatial conflict, automated parts and assembly production, construction sequencing and materials research and testing. (Garber, 2009) At architect now occupies the role of information mediator amongst the many disciplines and parties involved in 21st century design and construction.



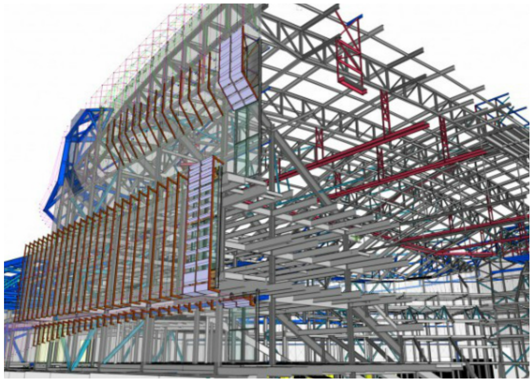


Figure 26 [Left]
The Tally Revit Plug-in interface developed by KieranTimberlake architects.

Figure 27 [Right]
Construction sequencing model for the Barclays Centre project by SHoP Architects

Simulation and information management tools have been widely regarded as a medium capable of enabling the architect to reaffirm their position at the center of the design process, becoming a central hub for which all information passes. Stephen Kieran and James Timberlake, authors of Refabricating Architecture (2004) argue;

> *"Today, through the agency of information management tools, the architect can once again become the master builder by integrating the skills and intelligences at the core of architecture. This new master builder transforms the singular mind glorified in schools and media to a new genius of collective intelligence. Today's master architect is an amalgam of material scientist, product engineer, process engineer, use and client who creates architecture informed by commodity and art." (xii)*

Inspired by the technological innovations of the aerospace, automotive and ship building industries, Kieran and Timberlake advocate for an architectural paradigm centered on the abilities of BIM to increase collaboration, communication and building quality. The authors refer to the "guiding lines of the information system" as the "new Modular", alluding to the fact that the architect's primary concern need no longer be proportion or form, but rather the processing and circulation of data. In this scenario, the architect emerges as a wielder of information rather than a creator of form. (Scheer, 2014)

The simulation considers all data to be of equal importance, thus eliminating hierarchal organizations of design considerations. Simulation does not favour one type of information over another. Similar to Turing's reasoning of Hilbert's Entscheidungsproblem, the simulation (or in Turing's machine) is incapable of prioritization unless such commands are instantiated in the system's logic. Building information modeling tools, while extremely powerful, remain indifferent to qualitative aspects of space, atmosphere and appearance.

Expression: A Taboo

With the widespread adoption of computational design strategies, the role of expression in contemporary architecture has been effectively muted. In a globalized society, regional styles are no longer relevant – today's paradigm is an epochal anti-style of disparate concepts and forms. The notion of form, while always present in any design is feared in all facets of contemporary architectural discourse. Architecture students are no longer critiqued on the formal quality of their proposals, but on the manifestation of their concept or the project's hypothetical functionality. Practitioners justify their 'contextually derived' designs with statistics and analytics. Theorists praise digital technology in its ability to increase automation and control towards the elimination of inefficiencies in traditional building procurement with little mention of the formal potentials these processes afford.

Simulation has suppressed the role of expression in today's digital paradigm. Richard Garber, in his essay Optimisation Stories (2009) speaks of the potential for BIM to revolutionize the role of the architect. In arguing for the performance-based benefits of BIM, Garber mentions, "an informed choice can be made from a family of related virtual solutions, and also serves to de-emphasize what perhaps was initially an interest in the formal aesthetic that also emerged from early studies of form generation and animation." The "blobitecture" and irrational forms that first emerged from early digital design explorations placed clear emphasis on formal quality over buildability. To adopt computational design strategies in mainstream architectural practice, these tools had to produce more than mere virtual visualizations - their value had to be predicated on notions of efficiency and optimization to gain traction in such an economically driven industry. What has resulted is an architectural paradigm where performance is celebrated and formal quality is largely suppressed. Today, the architecture industry is reluctant to justify 'good' design through formal quality, making efficiency a primary dictator of design quality.

Ironically, as architecture continues to evolve from modernism's functionalist doctrine, the digital era has given rise to a new *engineer's aesthetic* – an expression inherently founded in the functional performance of the building. Computation and simulation has enabled and expanded a social and cultural tendency toward the understanding of predetermined outcomes. Regardless of a new found interest in ideas like mass customization and variation, one could argue that architecture is continuing and accelerating modernism's infatuation with control, optimization and efficiency through mechanized processes of design and construction. (Marble, 2010) The same questions of technological determinism that surrounded industrialization have thus reemerged in the digital era. The machine that displaced the physical labour of the craftsman is now evolving toward a device with the potential of displacing human intellect. (Marble, 2010) As with industrialization, architectural culture is evolving in accordance with the tools available, imposing major repercussions on the traditional roles and responsibilities of the creator.

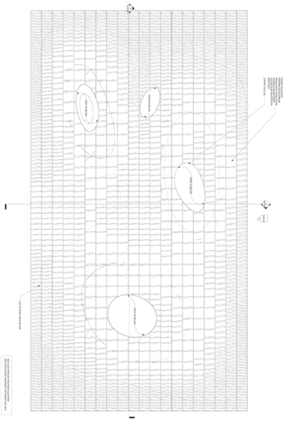
Considering the complex typologies, technologies and legal structures surrounding the architecture and construction industry today, the architectural discipline is dictated by the avoidance of risk, causing an infatuation with objectivity. The continuing trend is that architects demand certainty, thus driving the increased use of performance-based design software. Risk is to be avoided at all costs – clients and architects alike want to know what they're getting – structurally, aesthetically, operationally and financially. (Marble, 2010) Building information modeling, computational fluid dynamics and advanced energy simulation have given the architect new means of objective justification. The final building is no longer the prototype as the virtual model can predict performance with unprecedented accuracy. Risk is still associated with human input but shifts from the hand, with industrialization, to the mind in a computational design approach.

Form Follows Performance

Today architects have the resources to operate and design not solely on the basis of the needs of form as they pertain to structure, force and envelope, but instead on the environmental criteria and conditions that facilitate organizations and actions within the built environment. (Lally, 2007) Performative design refers to form finding strategies driven by functional criteria – structural capacity, thermal comfort, energy consumption, cost, time to construct and conformity to building codes are just a few examples of performance parameters commonly considered in this design approach. Performance has become a criteria by which design is evaluated – almost every aspect of the building's composition is justified through this quantitative lens. Where quantitative evaluation falls short, in the consideration of aesthetic and experiential 'performance', digital visualizations enable the evaluation and iteration of proposals in a virtual environment.

Leading practices tout their designs to be contextually derived, virtually optimized solutions, often producing thermal comfort gradients, axonometrics of building systems and solar radiance diagrams alongside seductive hyper-realistic imagery. In 2014, Fast Company dubbed SHoP Architects to be the most innovative architectural practice of the year, aptly noting that the firm has gone from "boutique to big commissions in only a few years". (Rosenfeld, 2014) SHoP has meticulously built a design brand centered on efficiency and optimization and are now firmly positioned as an elite global practice. The ability for SHoP to evolve from a four person outfit in 1996 to being named the world's most innovative in less than two decades is a clear indication of how deep performance optimization is entrenched within architectural culture today.

In a performance-driven paradigm, the traditional role of the parti has mutated from a symbolic representation to an underlying abstract logic. This logic, interacting with contextual data is curated by the



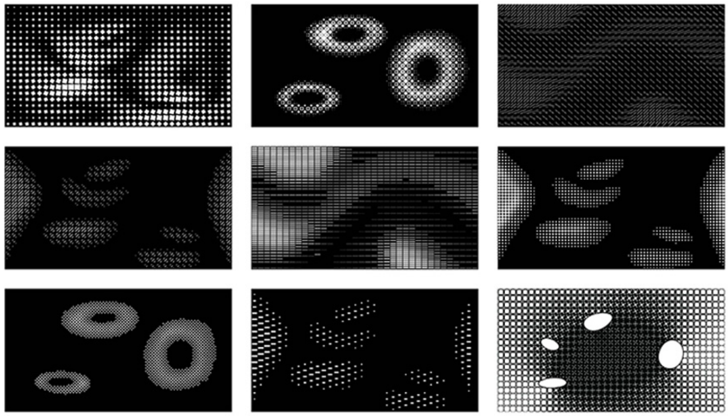


Figure 28 [Left]
Porosity study of SHoP Architects' canopy for the Konza Techno Pavilion

Figure 29 [Right]
Porosity study of SHoP Architects' canopy for the Konza Techno Pavilion

architect in all respects. The designer not only selects which data to incorporate and which to neglect, but also defines how the data is integrated and how the model responds to such inputs. In this light, qualitative decision making toward a particular formal expression still plays a large role in the design process. Architects are shifting the emphasis of their work away from subjective notions of form toward what is perceived to be inarguable correctness. In their informal manifesto; SHoP: Out of Practice, the firm's co-founders note, "Style is the mannered repetition of an aesthetic theme; it is the inverse of innovation. In taking design's visual means as an end, architects miss the opportunity to let how a building works, or how it is made, inform its appearance." (Holden, 2012) While it is of course the architect's moral obligation to instill value through performance and efficiency, one cannot relinquish formal expression to the computer simulation. In the current paradigm, the architect must straddle a constantly shifting threshold between quantitative determinism and qualitative reasoning.

Parametric design strategies have played a key role in reinforcing this culture, but pose much more potent value to architectural discourse at large. The output-driven perspective of performative design encourages the economization and narrowing of architectural thinking with regard to parametric design. (Kotnik, 2010) Where an aspect of a building is difficult to quantify, the performative attitude tends either to encourage the adoption of quantifiable proxies or relegate it to secondary status. (Scheer, 2014) The concept of functionality is not normative like in a performative design strategy, but rather an operative notion comparable to the traditional vague understanding of architectural *utilitas*. Only through a complex interaction of architectural and performative criteria throughout the design process can computational processes operate to their full potential – making it possible to unveil both the utilitarian advantages and inherent expressive qualities that the technologies enable.

Conclusions

Topical technologies have begun to introduce topics previously considered at the margins of the profession to inform how architects work today. The 21st century architect works alongside a myriad of consultants and stake holders never before present in architectural practice and previously peripheral subjects are gaining new relevance in their application to architectural exploration. Today's collective body of practice is an open-ended and recursive network of shifting boundaries in which the edge is a less useful, even irrelevant idea. (Kedan, 2009) This broad stream of inspiration and exploration has had a profound impact on the practice, profession and discipline.

For the first time, architectural practices are beginning to challenge the standardized regulatory, legal and communicative frameworks that have guided the profession for decades. Offices such as SHoP Architects are basing the very foundations of their practice on challenging the debilitating standardization of the industry. Another emerging trend is that of the "design-research" practice. Design firms are increasingly realizing the value of research as a critical component of their design pursuits. Cutting edge designers are beginning to structure their practices around what Michael Speaks refers to as "design intelligence" – internal research through design experimentation geared toward developing new modes of conception and construction while supplementing conventional income streams. (Speaks, 2007) These firms are collectively driving a broad reformulation of the idea of critical practice, with the aim of bridging the often separate sub-disciplines of theory and building.

The current context in which architecture is conceived, represented and built is on the verge of extreme change in accordance with emerging modes of design and practice. Specialized firms aid in the design and fabrication of complex forms, offices are contesting standardized contracts and legal structures, and design performance has become the architect's primary pursuit. With the exception of a small, yet continually growing, cohort of innovative practices across the globe, the AEC industry is still characterized by the antiquated modes in which the vast majority of buildings are designed and constructed.

04 | The Toronto MediaHub

The Toronto MediaHub (TMH) aims to become an exemplar of the technologies and activities hosted within. The building is to become a reference, a laboratory and a cultural destination allowing the public access to topical digital media and technology. Employing a series of parametric design strategies for its realization, the TMH showcases the capabilities of contemporary digital design and construction. The building, with its complex junctions, irregular composition and double-curved geometries, is only made possible through an iterative dialogue between designer and the computational tool. The proposal disregards the notion that plan drives form, supplanting this typical design method with one based on three-dimensional relationships and volumetrics - an approach only enabled (and facilitated) by the parametric design strategies employed.

Stemming from the project's philosophical foundations centered upon the relationship between human cognition and computational determinism, the design parti is inspired by the theme of duality and convergence. Architectural components weave and intersect in all dimensions from the macro scale of conceptual massing to the granular level involved in the design of refined architectural elements. The resulting proposal emerges as a series of fluid bands intersecting, peeling and merging to both veil and reveal solids and voids to create unique spatial conditions at the interior and exterior.

The Toronto MediaHub is envisioned as a dynamic mass negotiating the oblique corner of Lower Bathurst and Queen's Quay, intersecting with a secondary volume to the rear of the site to create interior spaces with framed views to the surrounding. The fluid language of the massing and envelope is echoed throughout the interior as ceilings, stairs, floor slabs and partitions work systematically to interweave, creating vistas, linkages and unique volumes throughout. The Toronto MediaHub proposal is the product of a complex network of interrelationships both internally amongst architectural elements and gestures, and externally between context and built form.

The Digital Library

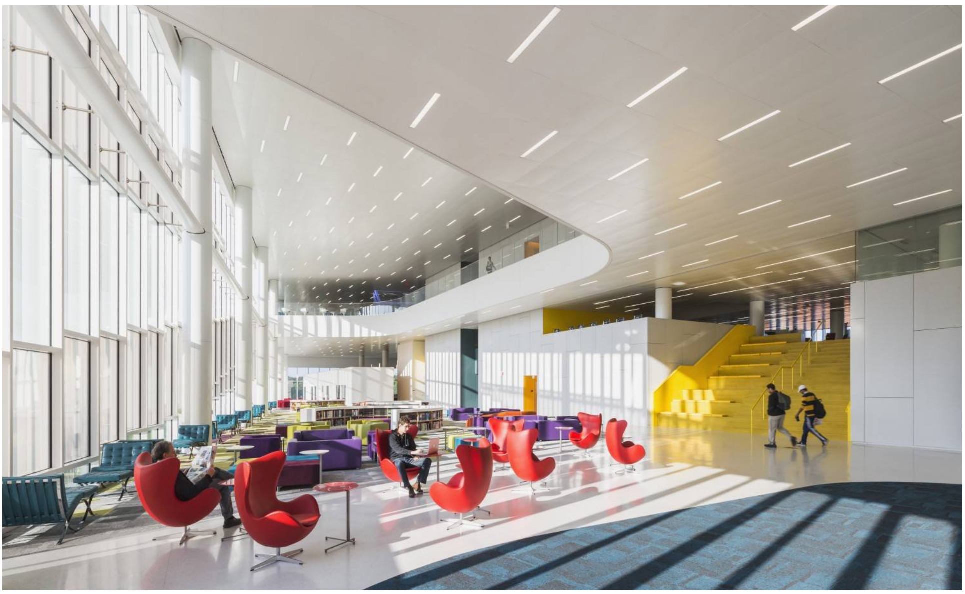
The ‘Digital Library’ as a typology brings forth a new idea of information centre - a physical space for the virtual world over the physicality of books and periodicals. In recent years, library use across North America has surged due to emerging digital needs and a widening divide between those whom have access to digital devices and the portion of society who lacks access to personal computers, laptops or internet enabled mobile devices. While libraries continue to endure heightened demand for access to their finite digital resources, many public library systems are being subjected to severe budget cuts causing reductions in staff, facilities and operational hours. (Hill, 2011)

While the library typology is certainly evolving, its role as a fundamental community amenity remains unchanged. Digital resources allow community members to browse available career opportunities in their area, research health concerns and contact friends and family abroad. In the United States, one third of Americans regularly use library internet access. 60% of these visitors used their browsing sessions to contact friends and family abroad, while 30% used their time to search for employment opportunities. (Hill, 2011) These figures indicate how the library is quickly becoming an essential resource for citizens across North America, allowing individuals to become effective members of their local and global communities.

Figure 30
Aarhus Urban MediaSpace proposal by Schmidt Hammer Lassen Architects

Cities across the globe are beginning to realize this fundamental shift in the function of the library. For example, in Aarhus, Denmark, the city has launched a community consultation process to envision a new digital library facility to meet the expanding and evolving needs of its citizens. The building, dubbed the “Aarhus Urban MediaSpace” will host a series of large community gathering spaces and a wide array of digital resources. A renaissance of library culture across the globe is occurring at the hands of media technology. The Urban MediaSpace is a primary example of how architecture can respond to this paradigmatic shift in one of the oldest cultural institutions in modern society. The library is no longer a repository for books and physical material, but rather a place for both social and digital interaction.

Figure 31
The James B. Hunt Jr. library by Snohetta Architects



The Toronto Context

The Toronto Public Library is the largest public library system in Canada with nearly 1.3 million registered borrowers and active users accruing approximately 19 million in-person visits per year. (Marriot, 2013) Currently, the Toronto Public Library has no plans on the horizon to create a dedicated facility for the ongoing digitization of their records and for community access to cutting edge digital media resources.

With nearly 1,800 internet work stations system-wide in 2012, the Toronto Public Library far surpasses any other Urban library system in the nation. Bibliotheque de Montreal placed at a distant second with a mere 400 workstations. (Marriot, 2013) This is to be expected from the public library of the nations largest metropolis, however many branches continue to experience severe budget cuts resulting in long wait lists, limited staff and reduced operational hours for many of these workstations and other digital resources.

Figure 32
Toronto Public Library's
Digital Innovation Hub

A recent $34 million five-year renovation to the Toronto Reference Library provides new study pods, automated stack shelfing, a series of group gathering spaces, an exhibition gallery and a digital innovation hub housing computers and 3D printing technology. While these renovations are indicative of an attempt to meet evolving community needs, branches across the city still operate in the conventional mode, with the vast majority of their sources being physical material.

Beyond the library system, the city of Toronto does have innovation based development on its horizon. With plans in place for a wifi connected community and technology corridor along the city's East waterfront, the city is aiming to develop a 21st century digitally connected urban community. The proposed Urban Data Library seeks to properly address the evolving needs of Torontonians. As the library moves progressively toward developing a digital resource database, physical space for the housing of hardware infrastructure will become a pressing issue. By creating a space not only for the storage and digitization of these resources, but also for the community to interact with virtual information.

Figure 33
Toronto Waterfront Innovation
Centre proposal by Sweeny
&Co Architects


Toronto Public Library

Surrounding Context

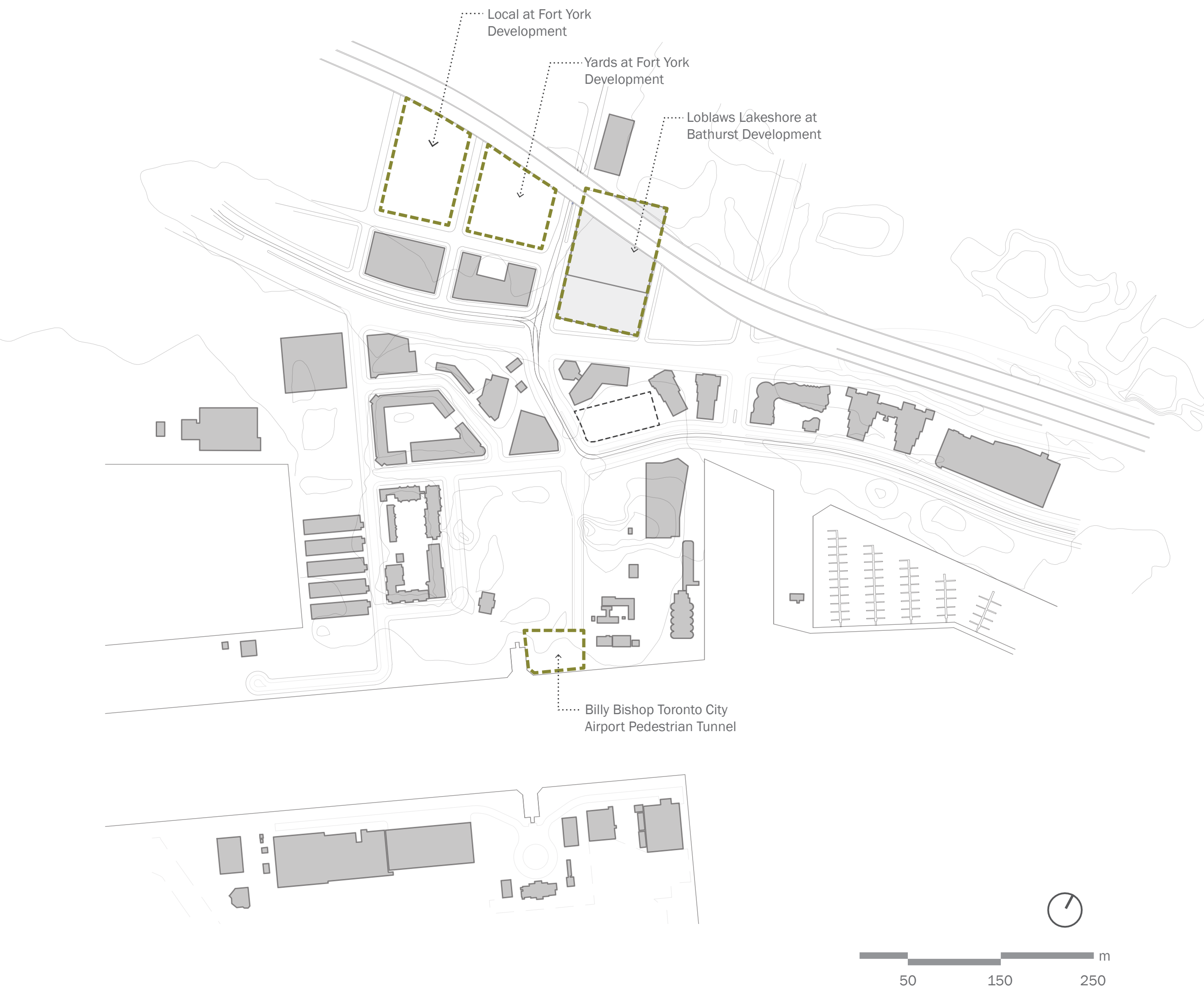
The proposed site is situated at the intersection of Bathurst Street and Queens Quay in Toronto, Ontario. Serviced by the 509 Queens Quay and 511 Bathurst Street streetcar routes and located steps from the Toronto Waterfront, the site provides ample opportunity to become a critical amenity to a rapidly intensifying community at the water's edge.

In a 2013 report on Land Use Evaluation for a potential Billy Bishop Toronto City Airport expansion, Urban Strategies Inc. makes note of rapid residential expansion with the study area bound by the Toronto Rail corridor to the North, the Don Roadway to the East, the Toronto Islands to the South and Marylin Bell Park to the West. From 2006 to 2011 the area experienced a 210% increase in residents (14,237 to 29,905) with an additional 22,258 future residents anticipated based on submitted development proposals. (2013) Considering the ever-growing residential density at the city's waterfront and lack of community amenities along Queens Quay, the site has the potential to positively benefit the immediate context while maintaining connectivity to the remainder of the city through transit connections to both the Yonge-University-Spadina subway at Union Station and the Bloor-Danforth line at Bathurst Station.

The site context features a wide array of typologies, including parks and recreation trails; boating and water-based recreational facilities; cultural and event spaces; housing; schools; commercial business and office space. With several completed and imminent revitalization plans in place surrounding Toronto's waterfront, the area is rapidly transforming into a mixed-use community at the water's edge.

In the immediate vicinity of the proposed site, a continuous mid-rise street face extends along the North extent of Queens Quay. These predominantly 8-12 storey mixed-use buildings are set back from the street, often featuring commercial business at grade. This pattern is somewhat interrupted at the intersection of Bathurst and Queens Quay West, where a large parking lot occupies the North-East corner.

Figure 34
Context Plan: Toronto Central Waterfront


Local at Fort York Development
Yards at Fort York Development
Loblaws Lakeshore at Bathurst Development
Billy Bishop Toronto City Airport Pedestrian Tunnel
m
50
150
250

0

624 Queens Quay West

Located at the North-East corner of Bathurst Street and Queens Quay, The proposed site at 624 Queens Quay West offers ample opportunity for the development of a public amenity to serve the immediate community and the city at large. The site is currently utilized as a surface parking area for an adjacent television broadcasting building to the North. The 2013 land use evaluation report by Urban Strategies Inc. notes, "there has been no declaration of development interest related to this site, but given its valuable location and the current development climate in Toronto it is reasonable to assume that the site will eventually be redeveloped." (2013) Considering it's prominence within the larger context of the city and its proximity to transit infrastructure, the proposed site is one of few locations currently undeveloped and offers a high degree of design potential.

Figure 35 [Left]
624 Queen's Quay West
At Lower Bathurst

Figure 36 [Right]
624 Queen's Quay West
Frontage at Queens Quay

The plot features prominent visual connections to Toronto's inner harbour, the iconic Canadian Malting Silos along Eireann Quay in addition to the Billy Bishop Toronto City Airport. The site's close proximity to the lake shore also provides results in a high degree of unobstructed solar exposure.

The site is situated within the City of Toronto's designated Harbourfront Zoning District. The Bathurst Quay Site is zoned for commercial-residential use, with a non-residential maximum gross area of 8500m^2. The site offers no maximum lot density for residential use.

With the recent completion of revitalization projects for both the Queen's Quay Harbourfront and the Billy Bishop Toronto City Airport Pedestrian Tunnel, the site offers the opportunity to become a prominent destination in the city. Acting as a gateway to the downtown core for patrons of the island airport and a well connected institution in a network of cultural facilities at the water's edge, the Toronto MediaHub has the potential to activate this currently underutilized site and its surrounding context while creating a landmark building that celebrates digital innovation.

Figure 37
624 Queen's Quay West
from Little Norway Park


DO NOT ENTER

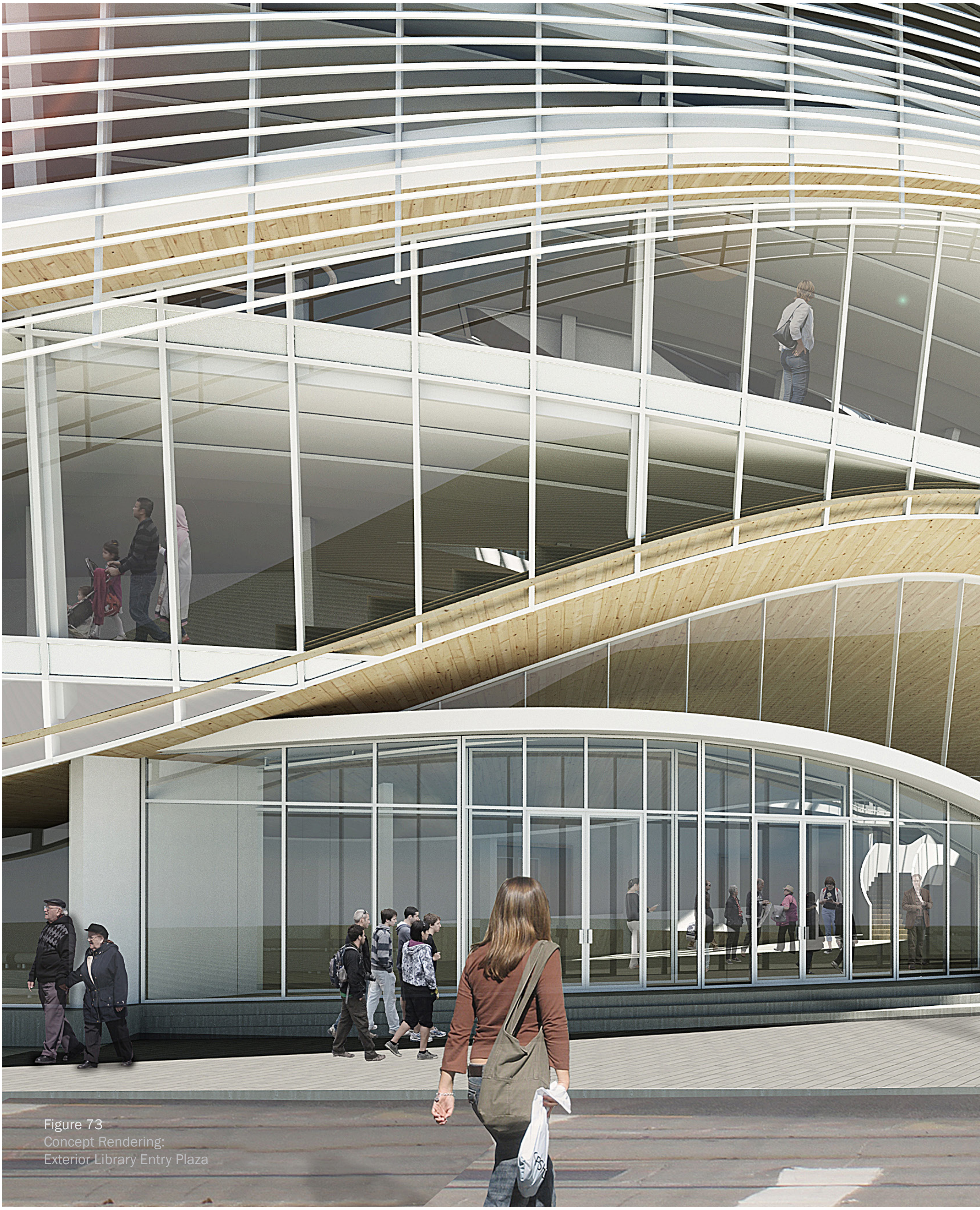


Figure 73
Concept Rendering:
Exterior Library Entry Plaza


waterfront

Design Strategies & Planning

The Toronto MediaHub is conceptualized as a form comprised of two serpentine masses, seemingly intersecting one another. The South mass peels away from grade to reveal entrances while creating varying degrees of shade and enclosure at the street face. The building's rear mass emerges above its counterpart to create a partial fifth level overlooking the centralized atrium and a South-oriented roof terrace, permitting views to the Billy Bishop Airport whilst allowing daylight to penetrate deep within the building's envelope.

The centralized atrium of the TMH design is surrounded by classrooms, meeting spaces, browsing areas, and media labs in addition to a series of open study spaces. Enclosed program spaces are distributed to the rear of the building, gaining natural light from the interconnected floor space. Open program is distributed along the South and West boundaries of the site, activating the street face while exploiting ample solar exposure of the waterfront location. The building's facade peels away from the structural plane to create framed views to the context from collaborative study spaces located within the junction of the two massing forms. Interacting with the building's overall geometry and interior programmatic arrangement, shading and glazing systems are strategically oriented to manipulate natural light conditions while curating views to the surrounding context.

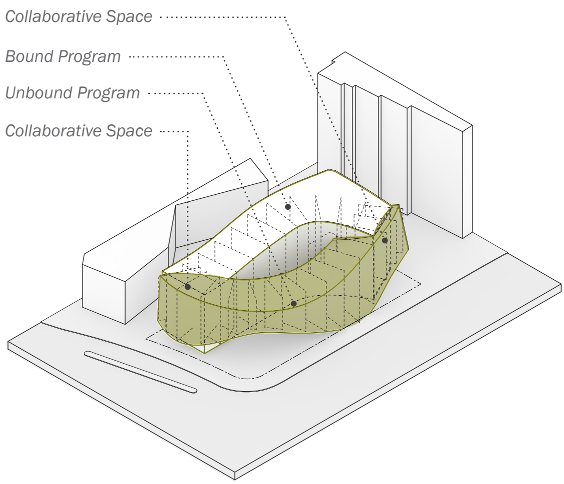
A main library entrance opens onto the intersection greeting visitors with an undulating soffit emerging from the ground plane. Two opposing stairs provide access to upper levels along the perimeter of the atrium as floor slabs protrude and retract to create seating areas and informal gathering spaces. This entanglement of floor slabs, structure, ceilings, stairs and railings is a microcosm for the complexity of the building's system-based design.

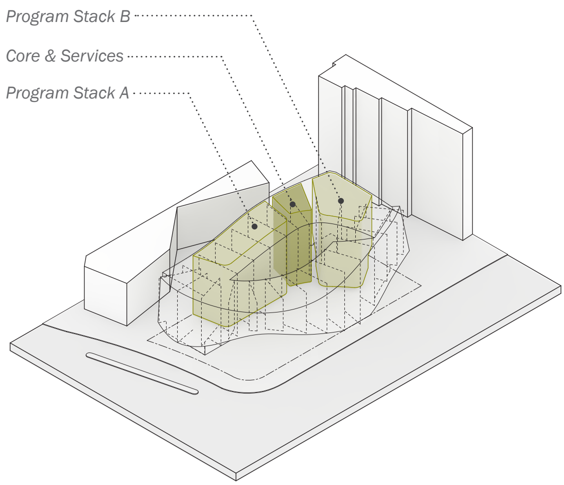
Figure 39 [Left]
Massing and program orientation

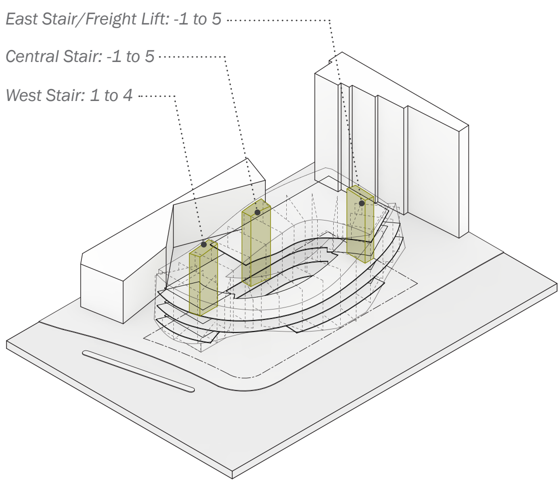
Figure 40 [Right]
Conceptual spatial planning

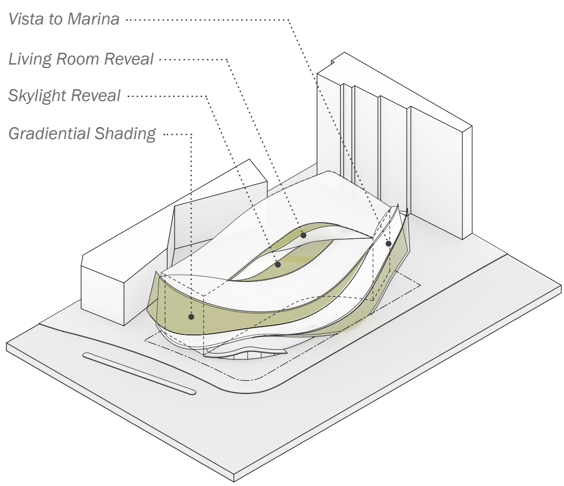
Figure 41 {Left]
Secondary Circulation Cores

Figure 42 [Right]
Glazing and louver distribution


Collaborative Space
Bound Program
Unbound Program
Collaborative Space


Program Stack B
Core & Services
Program Stack A


East Stair/Freight Lift: -1 to 5
Central Stair: -1 to 5
West Stair: 1 to 4


Vista to Marina
Living Room Reveal
Skylight Reveal
Gradiential Shading

Volumetrics & Relationships

Enabled by the use of a parametric design approach, the Toronto MediaHub proposal is conceived, visualized and refined in three-dimensional virtual space. Whereas traditional modes of architectural design and representation are limited to the two dimensional paper space, the parametric strategies employed facilitated the building's design through the analysis of volumetrics and sequential refinement of spatial conditions.

Parametric tools provided the means to realize the building's complex geometry in a high level detail, as building sub-systems and components are developed through a closely interconnected geometric logic. Architectural gestures within the building's exterior form are echoed throughout its interior spaces. An expansive soffit at grade lifts to create tiered seating areas at the second level, an undulating roof terrace creates sunken exterior seating areas and open height spaces below and a rear mass rises to form an intimate, naturally lit study space at the fifth level. The TMH proposal is the product of a design approach rooted in the manipulation of interrelated design systems toward a cohesive, functional programmatic response informed and guided by an overarching expressive intent.

An integral component in the building's volumetric design approach is the identification and management of relationships between building elements, while ensuring all repercussions of parametric manipulation are considered and mitigated. The building's overall massing, for example, is the key driver to structural divisions, floor plate boundaries and facade geometry, each component possessing a myriad of criteria to satisfy surrounding its function, constructability and expressive value. The parametric manipulations of each of the building's components are guided by the opportunities and limitations of tangentially linked elements toward the production of unique three dimensional spaces that emerge at both the building's interior and exterior.

Figure 43
Design Proposal
Exploded Axonometric

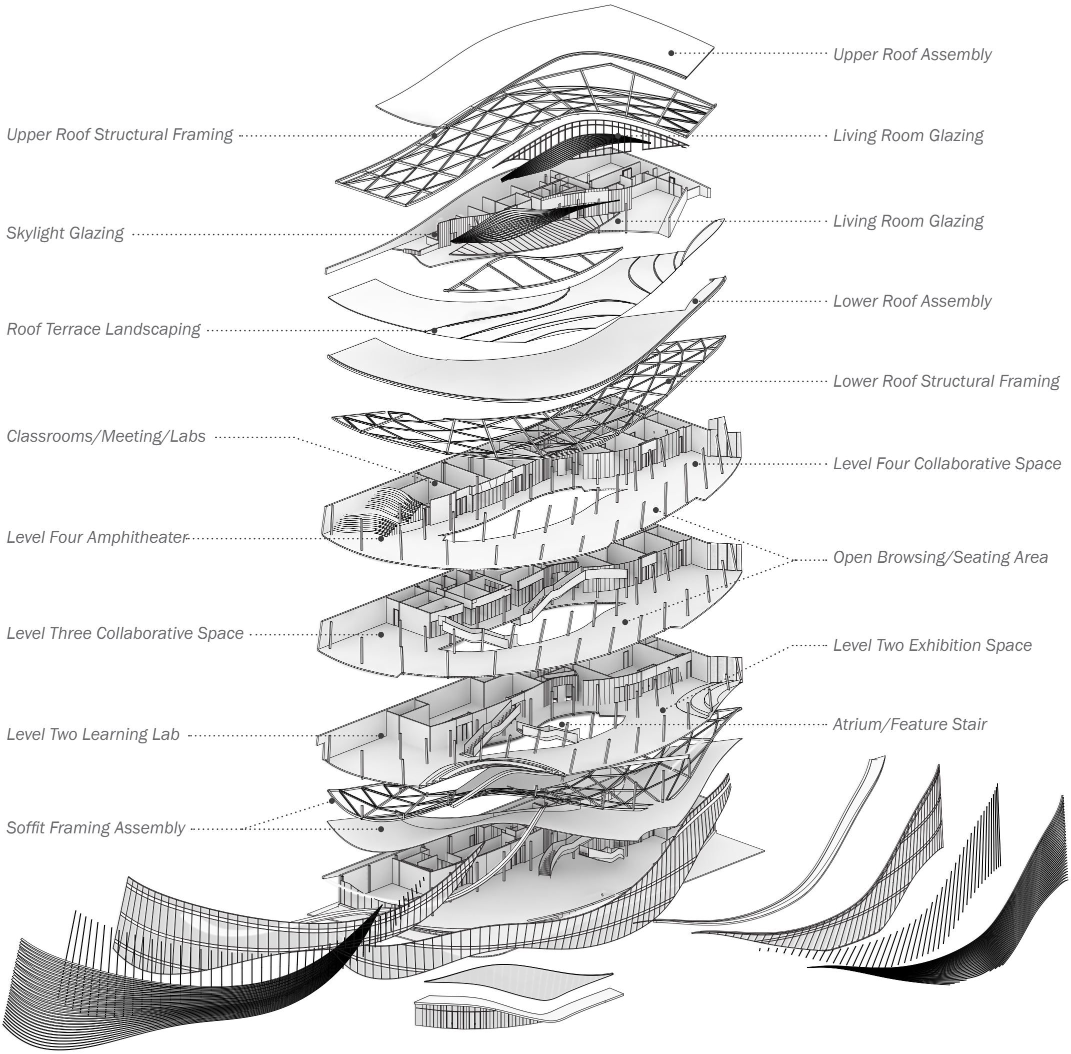

Upper Roof Assembly
Upper Roof Structural Framing
Living Room Glazing
Skylight Glazing
Living Room Glazing
Lower Roof Assembly
Roof Terrace Landscaping
Lower Roof Structural Framing
Classrooms/Meeting/Labs
Level Four Collaborative Space
Level Four Amphitheater
Open Browsing/Seating Area
Level Three Collaborative Space
Level Two Exhibition Space
Level Two Learning Lab
Atrium/Feature Stair
Soffit Framing Assembly

Figure 44
Concept Rendering:
Exterior from Little Norway Park

Building Design Methodology

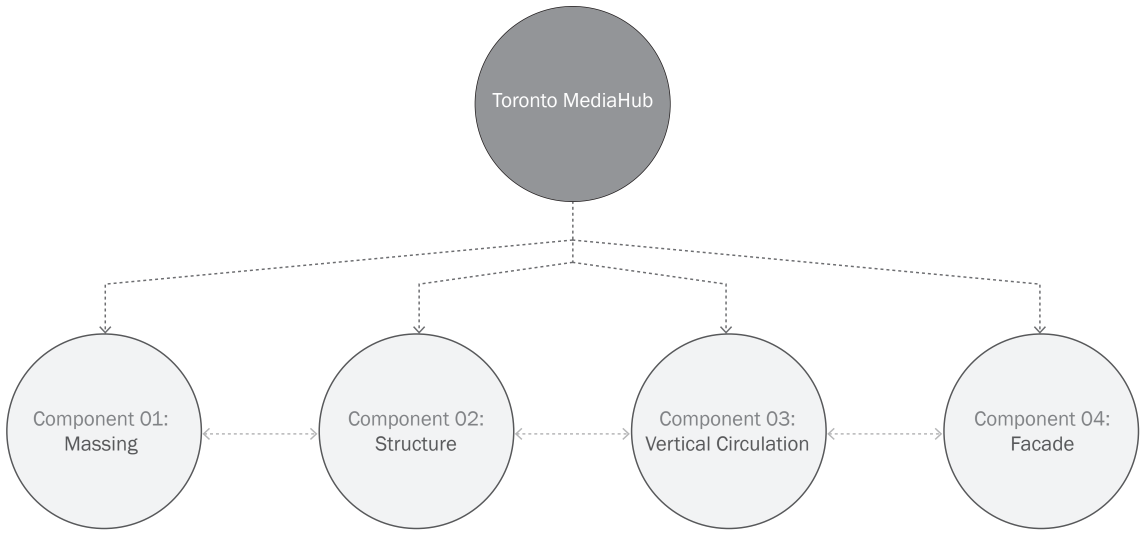
The design proposal is realized through a series of mutually interdependent components that are each developed through the use of parametric design processes. While this design strategy is employed to develop nearly all elements of the building, four sub-systems of the proposal are identified and analyzed with respect to how the designer interacts with the computational model toward a particular expressive intent. The design of these elements; building massing, structure, facade and vertical circulation - is documented in detail and cross-referenced with a hypothetical conception of the computational design process as demonstrated in Figure 03.

These sub-components are networked - live-feeding updated information, ensuring all building components are evolving simultaneously in accordance with altering parametric inputs. Each facet of the building's design is addressed interdependently with the remaining three. The design methodology is to document how the overall building intent is pursued within each parametric definition and evaluated both as whole and on a per-component basis, effectively unveiling the complex symbiotic relationship between the designer and the computational model.

Each component of the building's design is documented and analyzed with respect to how the designer cognitively interacts with the computational construct to conceptualize, develop, iterate, select and refine a final scheme.

The process of each design component is cross-referenced with the proposed map of a parametric design process. By pursuing this design strategy in five separate, yet closely interlinked facets of the building's composition, it is possible to evaluate where cognitive decisions and generative computation take place in the digital design process.

Figure 45
Building Design
Methodology


Toronto MediaHub
Component 01:
Massing
Component 02:
Structure
Component 03:
Vertical Circulation
Component 04:
Facade

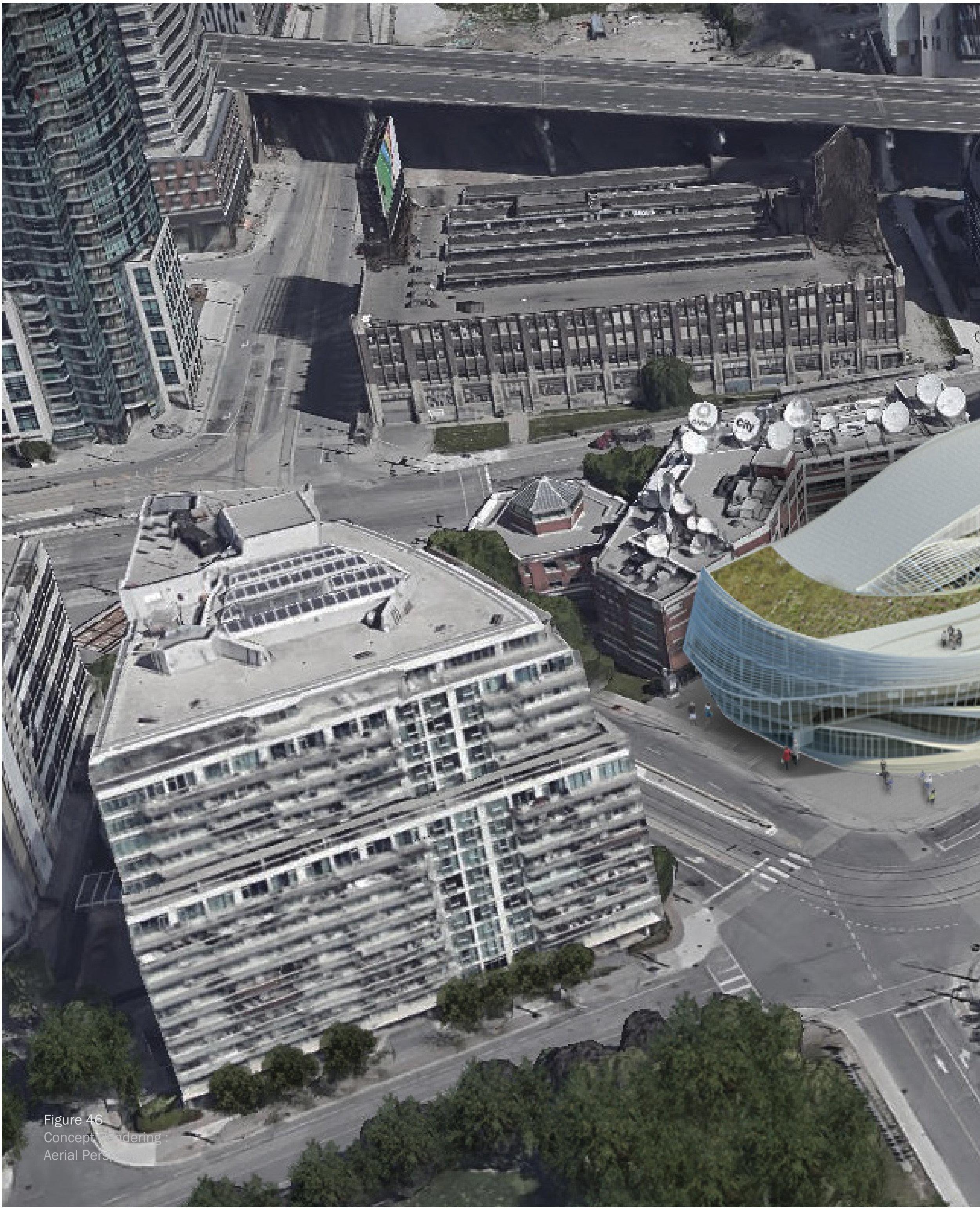


Figure 46
Concept Rendering :
Aerial Pers

Intent

Abstract representation of two masses

Considering the theme of duality in the building's parti and the irregular shape of the site, the desired massing is to be composed of two distinct forms. These masses are to weave amongst one another as amorphous volumes to create varying spatial conditions throughout.

Dynamic Form

The building's form is imply motion to reinforce the expression of convergence. The fluidity of the building massing is also an expression of the tools employed in the process. By avoiding platonic geometries in favour of complex intersections and double-curved surfaces, the building imbues the innovative technology and activities hosted within.

Surrounding Sightlines

The building massing must be conducive to creating open vistas to key contextual landmarks including Little Norway Park, Billy Bishop Airport, the Canadian Malting Silos and Marina Quay West.

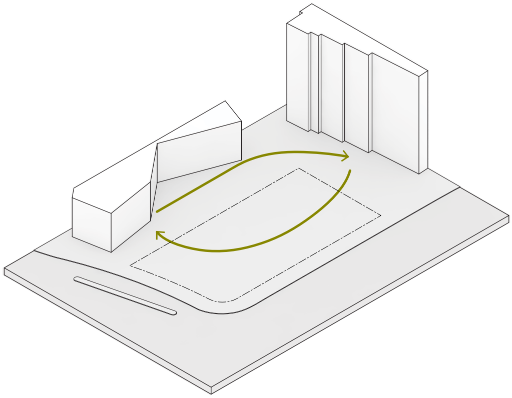
Engage the Street

Whereas much of surrounding built form is set back from the street and largely buffered by courtyards and semi-private walkways, the TMH proposal is to engage the street, creating overhangs in addition to direct visual and physical connections between interior and exterior.

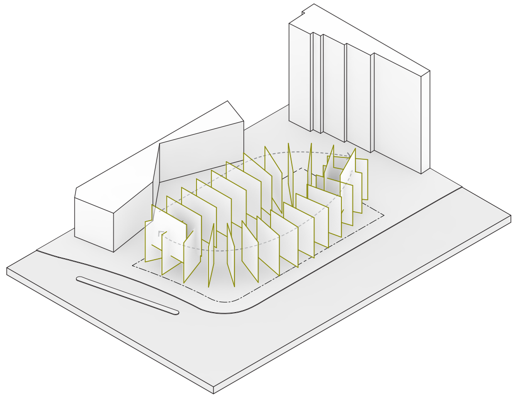
Logic

Inspired by Kas Oosterhuis' conception of the 'power line', the foundational input for the massing logic is a pair of planar curves that dictate the entire building's geometry. A series of sectional planes are radially distributed along each curve, creating two co-planar extrusions. The edge curves of each extrusion are manipulated in the z-axis with a series of control points to create undulating surface conditions. The resultant curvilinear geometries are manipulated and evaluated in relationship to one another as well as the ground plane condition. Sectional frames are then extrapolated from both masses and rotated based on a series of attractor points, creating further undulation in the X-Y plane. The location and intensity of rotation is iterated in close relationship with edge curve manipulation.

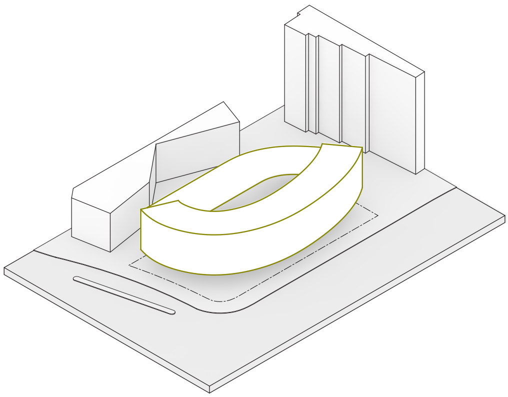
Figure 47
Massing Scheme
Geometric Logic



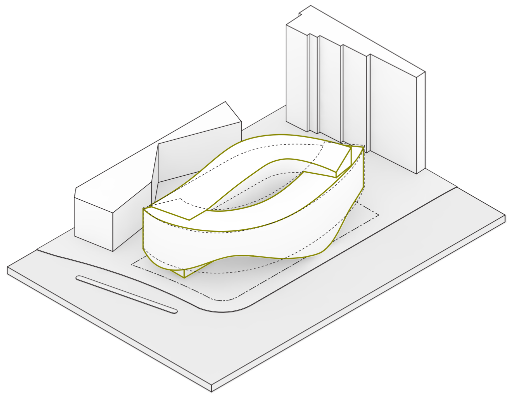
47a: Establish Power Lines



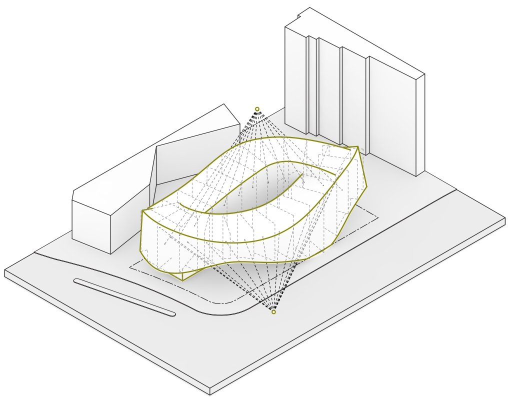
47b: Orient Perpendicular Frames



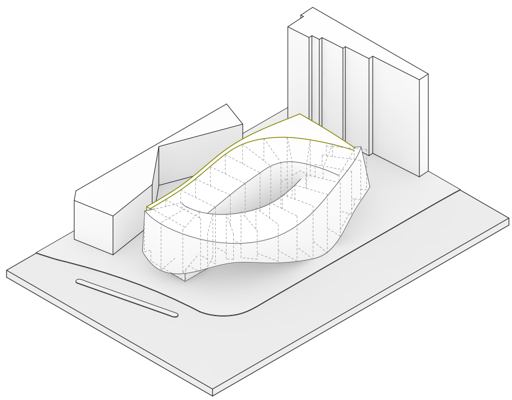
47c: Loft Frames



47d: Edge Curve Manipulation



47e: Frame Rotation & Rebuild



47f: BOH Infill

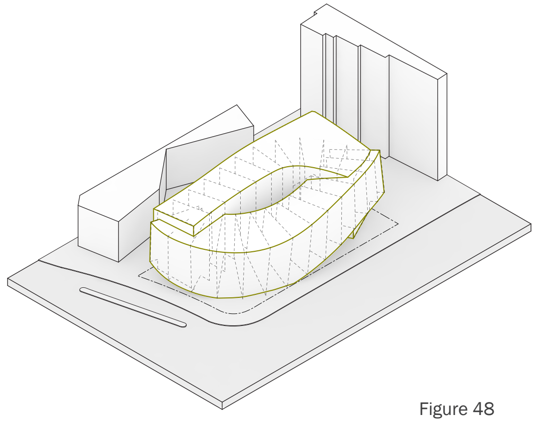


Figure 48
Massing Scheme A
East Incline - Positive Rotation

Iteration & Evaluation

From the massing logic, a series of iterations are generated each conforming to the geometric principles outlined in the developed framework. Each iteration is evaluated based on performative and functional potential in addition to the outlined design intent. The massing iterations are evaluated by the designer's qualitative judgment from both the perspective of exterior proportion and interior volumetric conditions.

Each iteration is evaluated with specific attention how the form addresses the street face from off-site visual perspectives and conditions immediately adjacent the site. Resultant atrium configurations are also a key concern as varying rotational values and attractor point placements each significantly impact the massing's sectional profile. Negative rotations resulted in tapering of the void to the upper extent, therefore creating a greater degree of enclosure. Edge curves are also manipulated to evaluate porosity and soffit elevations at grade relative to desired overhang conditions. With the manipulation of different parameters within the logic, previously unknown patterns and relationships begin to emerge, informing further iterations of the parametric model.

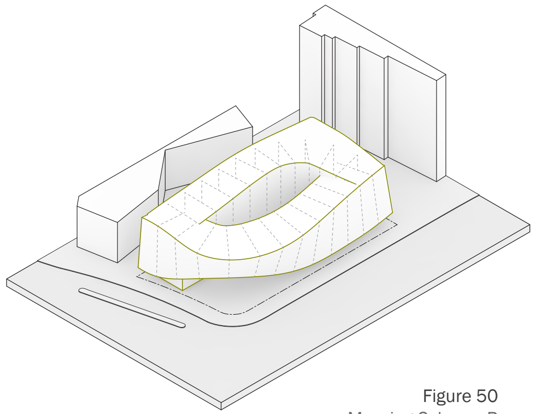


Figure 50
Massing Scheme B
West Incline - Positive Rotation

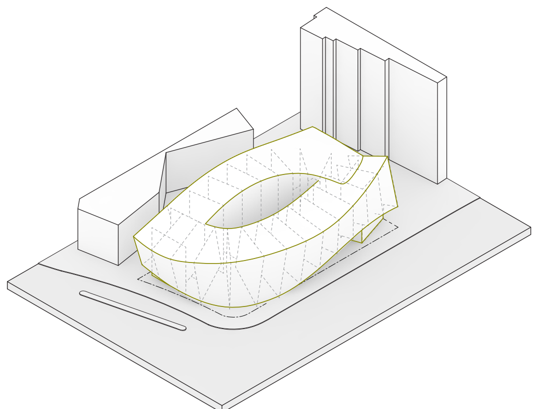


Figure 52
Massing Scheme C
West Incline - Negative Rotation

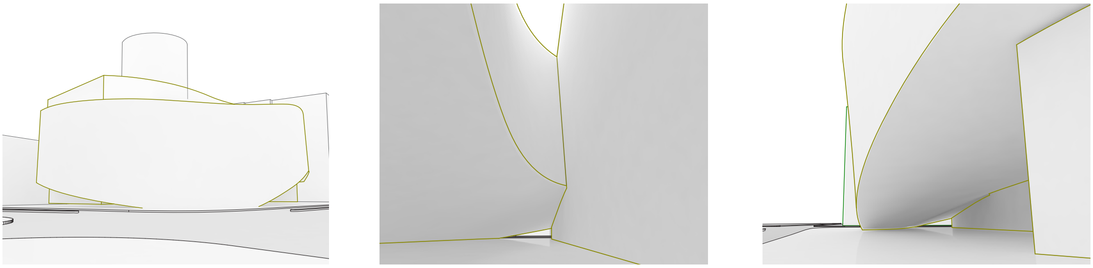


Figure 49
Massing Scheme A
Spatial Evaluations

Figure 51
Massing Scheme B
Spatial Evaluations

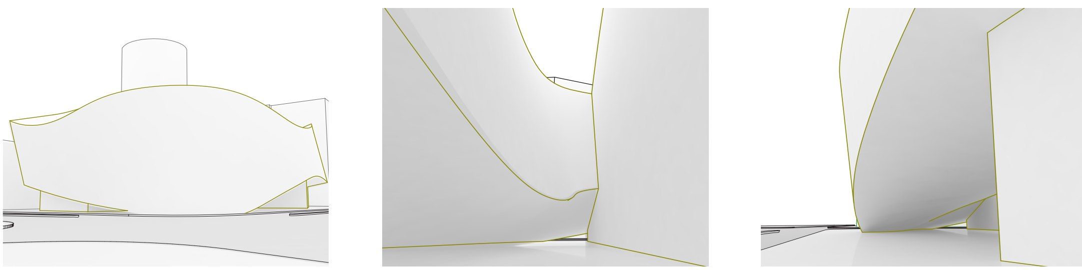


Figure 53
Massing Scheme C
Spatial Evaluations

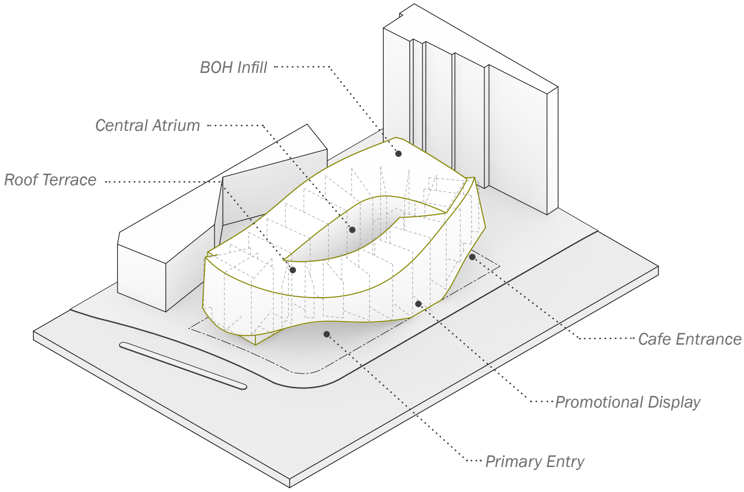


Figure 54
Developed Massing Scheme

Selection

The proposed massing scheme is selected based on manipulation of proportions and satisfaction of architectural concerns that lay beyond the scope of the geometric logic. The form features a primary entry opening to the adjacent intersection and a secondary reveal for retail or commercial functions at grade. In anticipation of interior programming, the rear mass is configured to span linearly along the North extent of the site, allowing for rational distribution of bound program, structure and building cores. The elevation of the rear mass is also configured in such a way to allow a point of access to a South-facing roof terrace while permitting views throughout a tapered atrium space.

Reflection

The massing scheme's development poses several challenges typically absent in traditional design processes. The building massing is arguably one of the most abstract components of an architectural design - it can assume virtually any formal language; rectilinear, faceted, amorphous, or combinations of such. The massing scheme relies heavily on primitive sketches to inform its foundational logic, in turn producing mutated versions of the original sketch description. It is critical that prior to beginning the development of any geometric logic, the designer is armed with an explicit understanding of what is desired. In addition to accounting for external contextual factors, speculative planning of floor elevations, interior program and facade configurations also inform the parametric iterations. During early development, structural considerations proved a major factor in how to rationalize the building's double-curved surfaces. As the primary geometric driver of the building's form, the massing logic must consider how and where to establish linkages to other building sub-components.


Figure 55
Concept Rendering:
Level Four Atrium

Intent

Expressive of Massing

The structural scheme is to be closely interlinked with the building's massing geometry, becoming a medium for which to continue the language of the exterior throughout interior spaces. As opposed to superimposing a traditional rectilinear grid upon a complex three dimensional geometry, the structural elements are to conform to its surfaces rather than relying on irregular cantilevers to negotiate undulating envelope geometry.

Long Span Framing

Considering the amount of required open seating space, browsing stations and study areas in the building program, the structural design is to minimize floor plate obstructions. Various reveals generated by the massing form at the ground plane are to be supported with minimal use of columns to create the illusion of a floating mass above grade.

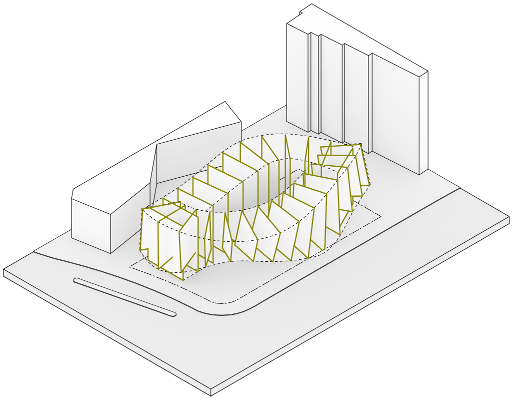
Topologically Variable

Employing a parametric approach in designing the building's structural system, structural framing elements are to be developed as a singular topology with the ability to negotiate the massing's complex curvature. By creating a series of topologically identical framing segments tied to the building's overall form, the structural system creates levels of variation clearly discernible from both interior and exterior.

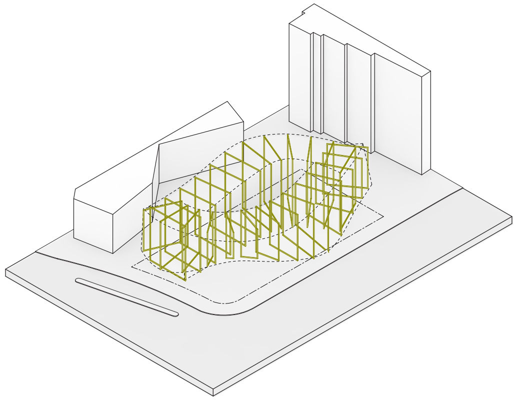
Logic

Directly linked to the development of the building's massing, a series of sectional frames splayed along each mass form the basis of the structural logic. Edge conditions of each frame are extrapolated, offset and extruded to form a rectilinear sectional profile. Each extruded frame is then intersected with a series floor slabs whose elevations are dictated by parameter input. Slab edge conditions are then developed relative to girders, massing geometry and primitive developments of the facade. Sectional frames are cross-braced through an alternating succession of linear members at the roof and ground floor soffit condition. Through this logic, the frequency of cross-bracing is manipulated with a parametric value to accommodate a varying curvatures degrees generated by the massing model.

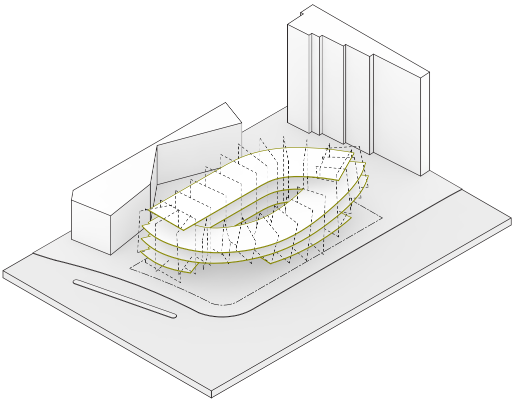
Figure 56
Structural Scheme
Geometric Logic



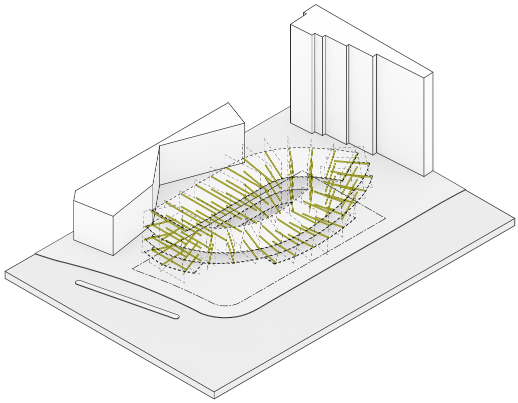
*56a: Rotated Frames [*Massing]*



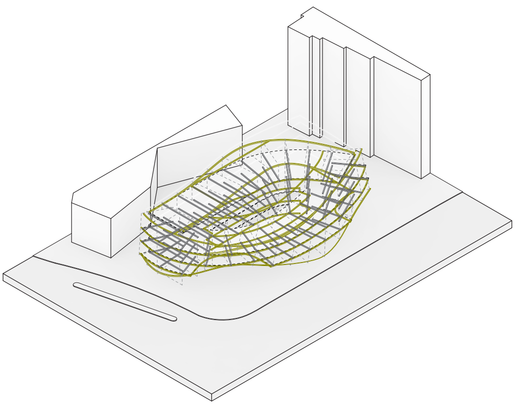
56b: Extrude Raw Frames



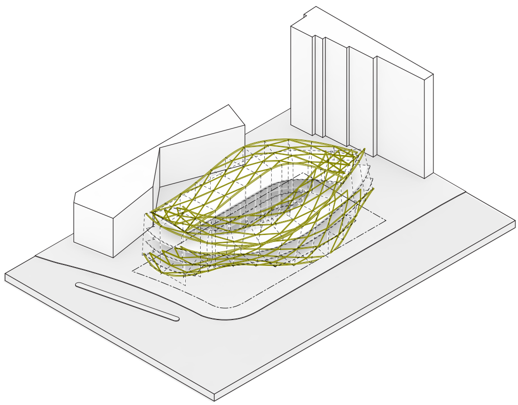
56c: Intersections & Girders



*56d: Slab Edges [*Massing]*



56e: Secondary Framing Elements



56f: Alternating Cross Bracing

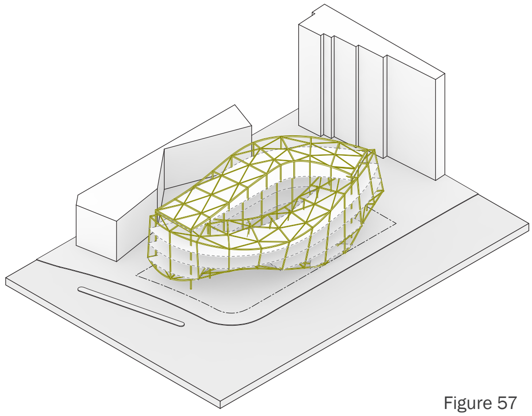


Figure 57
Structural Scheme A
Minimize Grid and Cross-Bracing

Iteration & Evaluation

Developed in part alongside the building's massing scheme, the structural system is iterated based on differentiations in the massing form and internal parametric values such as member spacing, sectional profile, and floor elevations.

Each iteration is evaluated in consideration of spatial conditions created along the South mass in addition to its potential for accommodating a central stair within the atrium void. Cross bracing is also analyzed and iterated to achieve an optimal resolution for the building's desired curvature through a series of linear members.

Through a process of iteration and evaluation, unique, unforeseen relationships between the massing and structure iterations become apparent. For example, the rotational value of each massing scheme dictates the angular incline of each column member. By assigning a negative value to the rotation, columns along the South mass angle inward as they ascend the atrium, generating a narrowed floor plate and widened ceiling above. Floor slab elevations are determined based on desired gross floor area and spatial conditions relative to the massing curvature. Preliminary interior planning considerations throughout the building play a significant role in the evaluation of each variant.

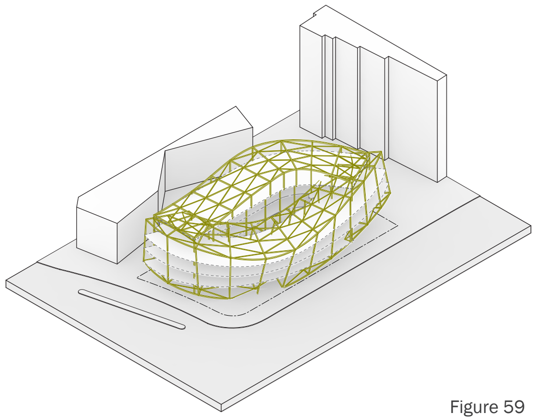


Figure 59
Structural Scheme B
Maximize Span and Volume

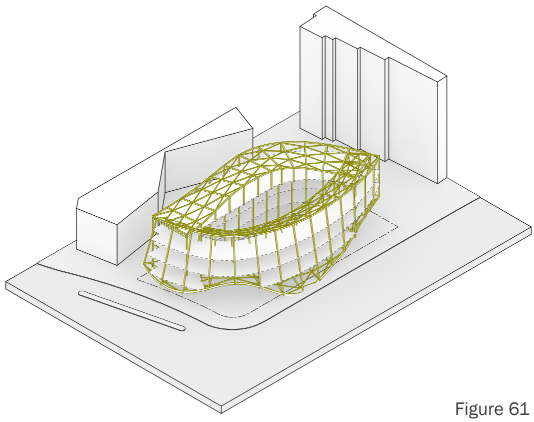


Figure 61
Structural Scheme C
Maximize Frames and Cross-Bracing

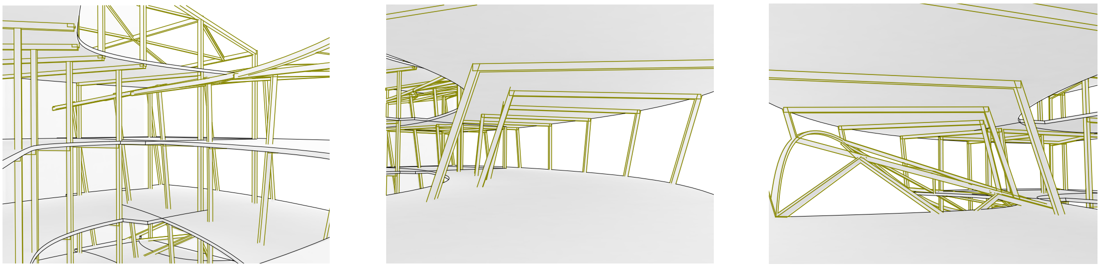


Figure 58
Structural Scheme A
Spatial Evaluations

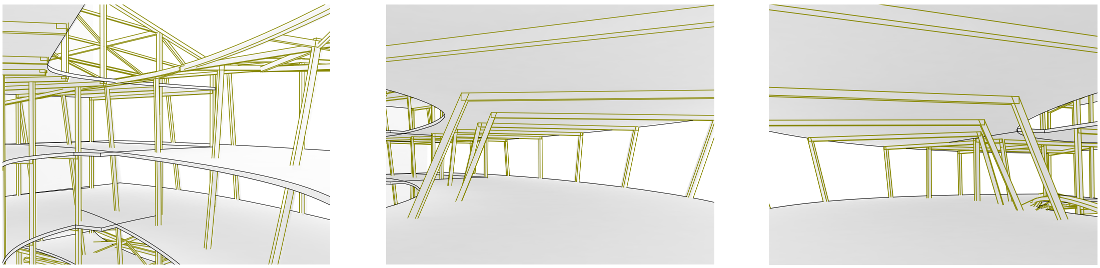


Figure 60
Structural Scheme B
Spatial Evaluations

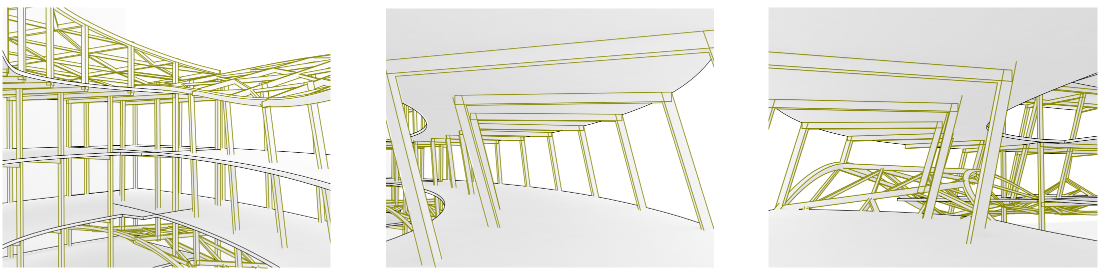


Figure 62
Structural Scheme C
Spatial Evaluations

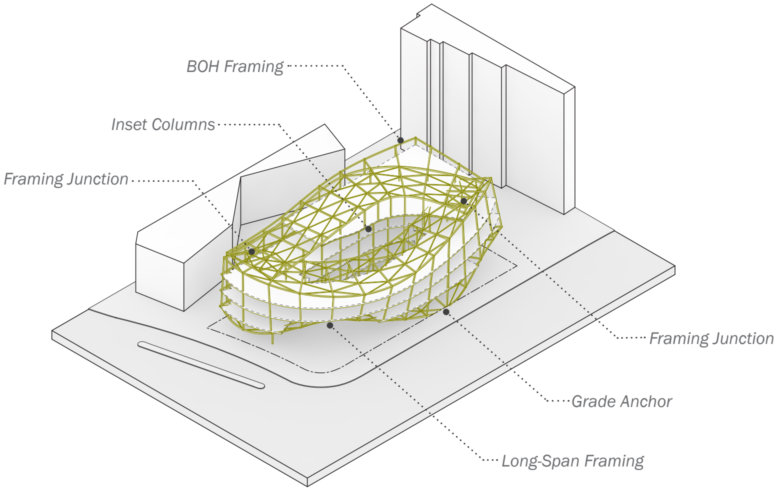


Figure 63
Developed Structural Scheme

Selection

The proposed structural scheme gives careful consideration to the location and spacing of columns at grade, allowing potential anchoring points for long-span soffit reveals. At the interior, visible columns are distributed to maintain desired proportions, with the combined manipulation of both sectional profile and frame frequency. Slab elevations are optimized to create undulating ceiling conditions at the upper levels of the building while maintaining functionality of spaces.

Reflection

The structure's parametric scheme is developed in parallel with the massing model - the two components bonded by a mutually informative relationship. Straddling the design of both the overall massing and interior planning, the structural system is iterated and refined to account for oversights in the original design that become apparent only after developing primitive iterations of the logic. These factors not only demanded a reiteration of the generated proposals but also a revision to the geometric framework itself. As the design evolves toward a more granular level of detail, it is also critical to identify when to abandon the parametric model in favour of manual methods of refinement. Considering the irregular transition to the North-East corner of the site, the geometric logic accounted solely for the radial structural members whereas rectilinear bays of the rear service areas are manually modeled based on guidelines produced by the logic. The complexity and interaction of each scheme is therefore contingent on the designer's curation of considerations toward a streamlined model free of any superficial parameters.

Figure 64
Concept Rendering:
Level Two Atrium


Lecture
Theatre
TORONTO
PUBLIC
LIBRARY
Harbourfront MediaHub

Intent

Bi-Directional and Opposing

The central feature stair is to be divided in two sets of rises in an attempt to express the overarching concept of duality and convergence. Each floor is to be served by two stairs at opposite extents of the atrium perimeter, maintaining equal distance between landings at each level.

Create Space

The feature stair is to be employed as a means of defining space at all levels of the building. Each stair is to be manipulated toward the creation of informal program spaces situated below, between and above each instance.

Conform to Geometry

The stair geometry is to correspond to both massing and structural schemes aligning to the interior surfaces of the atrium, echoing the formal language of the exterior throughout interior elements of the building.

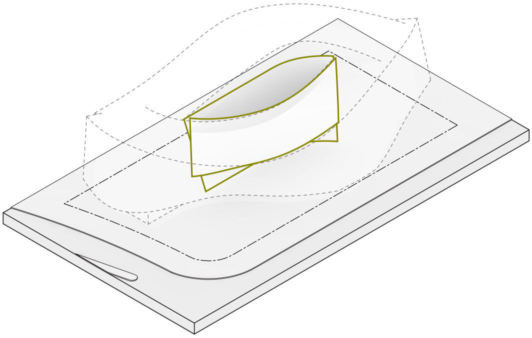
Stair as Sculpture

While maintaining the formal language of the building parti, the feature stair is to read as a separate expressive element from the surrounding structure. The sculptural element is to serve as a focal point within the atrium providing visual connections throughout the building's interior.

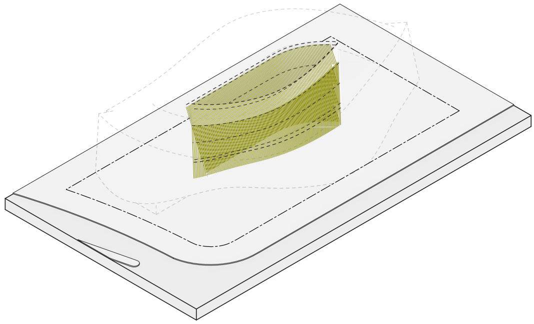
Logic

The feature stair scheme is developed through a logic based on the interior surface curvature of the building massing and it's intersection with floor plates. Slab edges at the atrium are subdivided to create a series of points that inform the placement and distribution of each span while also relative to structural framing elements. Mid-points of each base curve are offset and shifted to form the riser path for each stair instance. Pulling floor elevations from the structural scheme, the logic automatically computes the required number of treads and risers based on the input of maximum and minimum values, generating a planar mid-landing from the remaining length of the base curve. Tread extents are then interpolated, translated and lofted to generate fully adjustable guards and soffits.

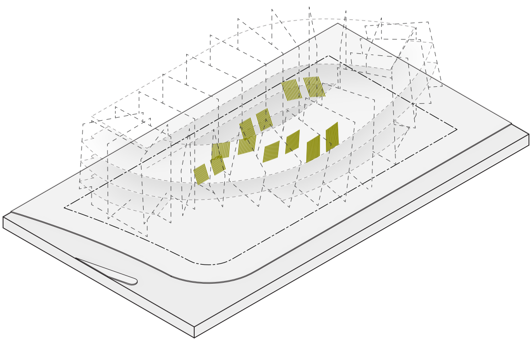
Figure 65
Feature Stair
Geometric Logic



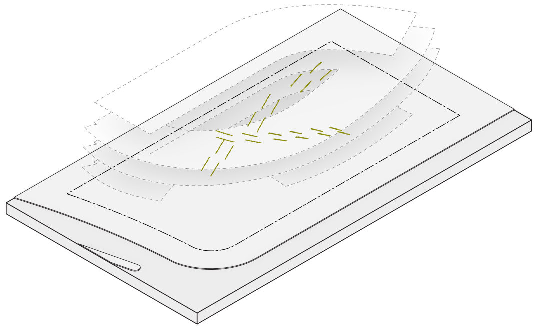
65a: Extract & Trim [*Massing]



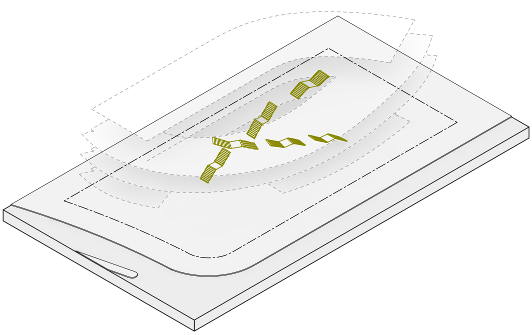
65b: Extend & Divide



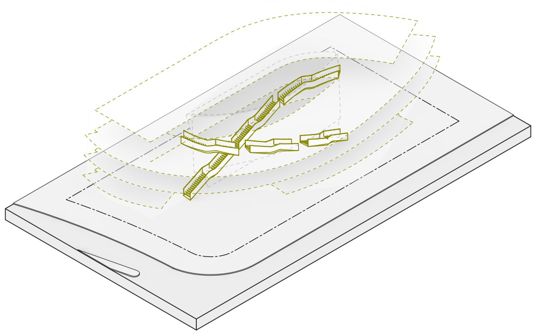
65c: Trim & Select



65d: Divide & Interpolate



65e: Offset & Loft



65f: Interpolate & Panelize

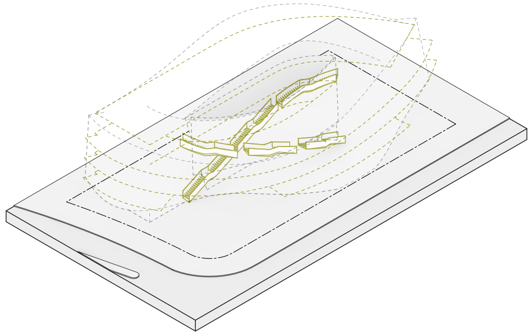


Figure 66
Feature Stair Scheme A
Linear Ascent - Full Conformity

Iteration & Evaluation

The development of a highly resolved yet streamlined logic for the feature stair permitted the rapid iteration and evaluation of the building component relative to interior spaces, structural members and atrium geometry.

Informed by spatial programming at the ground level, the stair logic is utilized to explore varying options for how to address both the primary West entry and secondary access to the East relative to seating areas and potential locations for the service desk. Way finding, site lines and the creation of space at the ground level are key qualitative considerations made in the evaluation of each scheme.

The iterations also provide the opportunity to evaluate the resultant spatial affects of extending each stair into the atrium space to varying degrees. By shifting the distribution and projection of each base curve, it is possible to assess each scheme to eliminate conflicts, clearance obstructions and undesired junctions while assessing how each stair relates to the spatial planning and composition of the building in its totality.

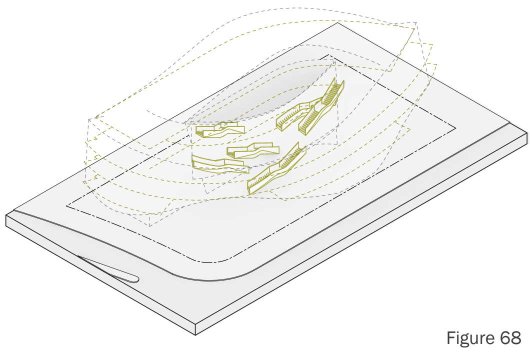


Figure 68
Feature Stair Scheme B
Staggered - Full Conformity

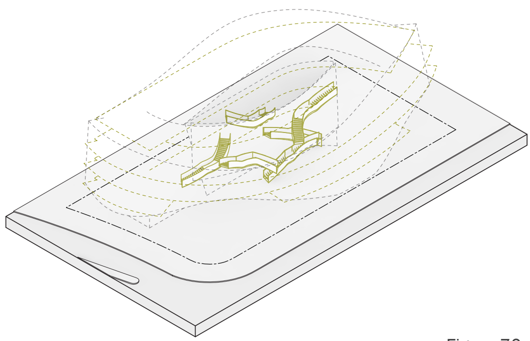


Figure 70
Feature Stair Scheme C
Staggered Minimal Conformity

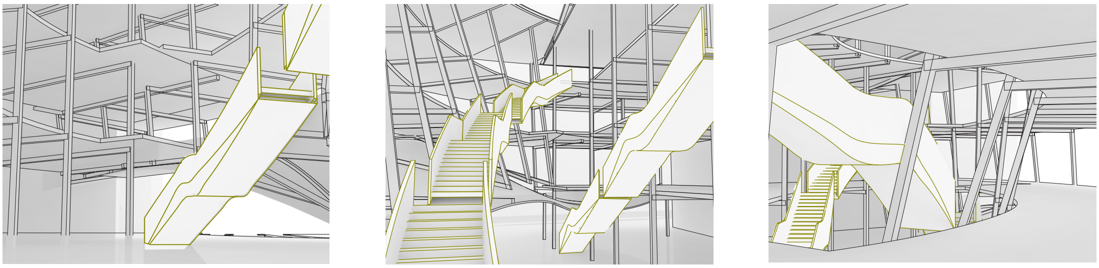


Figure 67
Feature Stair Scheme A
Spatial Evaluations

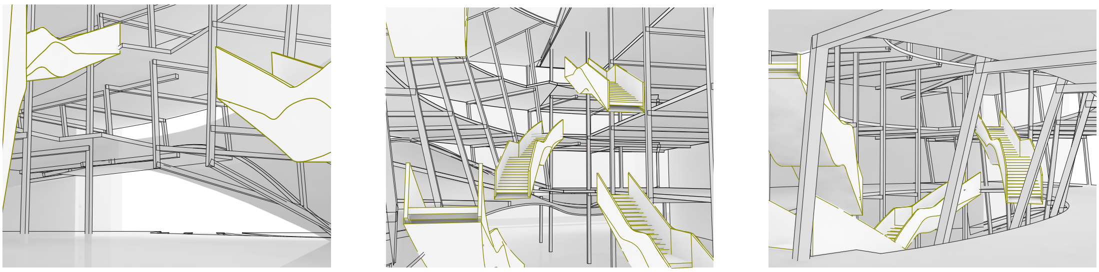


Figure 69
Feature Stair Scheme B
Spatial Evaluations

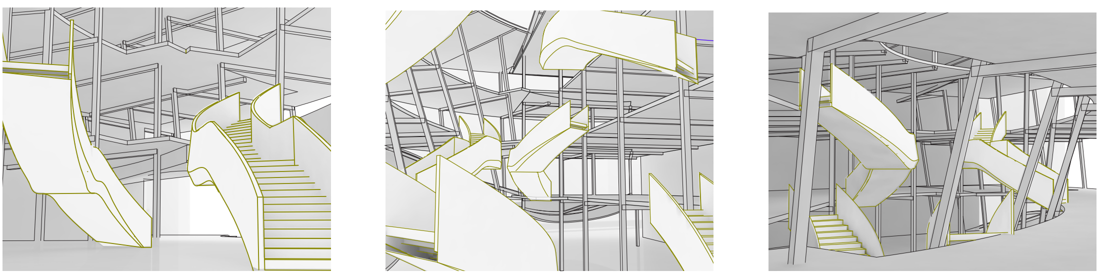


Figure 71
Feature Stair Scheme C
Spatial Evaluations

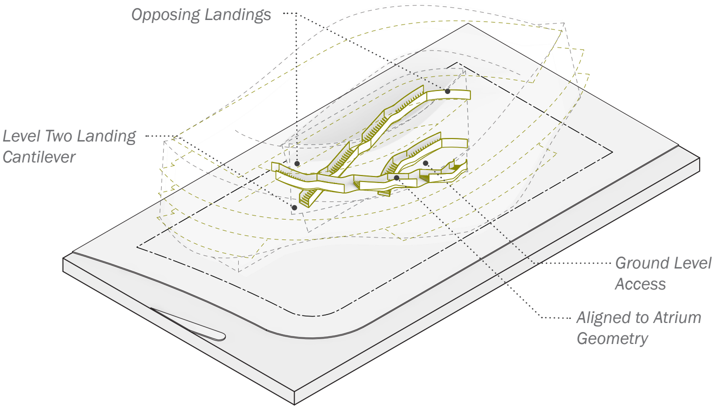


Figure 72
Developed Feature
Stair Scheme

Selection

The final feature stair scheme features a linear procession along opposing extents of the atrium. Two stairs peel away from the massing geometry at grade to create an informal gathering space in between, while floor slabs above weave amongst the linear arrangement. The configuration eliminates obstructions within the atrium, maintaining visual connections throughout. Upper stair components adhere tightly to the massing and structural geometry negotiating double-curved level-to-level transitions along the South face of the atrium space.

Reflection

The design of the feature stair sheds light on how building elements evolve within a design system throughout the proposal's development. Preliminary intentions for the stair are centered on conformity to the building's interior massing surfaces. As the interior planning evolves to a finer level of detail, the stair positioning, width and relativity to floor slabs are reiterated to suit. Early iterations featured a full-height linear procession along opposing edges of the central atrium. The planning of entrances and sight lines at the ground floor demanded a more flexible logic capable of diverting from the massing faces. The logic is iterated to allow more flexibility and differentiation from floor slabs, whereas a series of sub-notations are integrated for stairs to adhere and ascend the upper atrium's double-curved profile. This constant recursive process also allows for the streamlining of the parametric model as the design progresses. Following the development of floor slabs and structural elements, the it is possible to simplify the stair's logic by extracting new inputs from adjacent elements to eliminate unnecessary considerations integrated within the original model. As the building evolves as an interconnected system around each particular element, all aspects of the process - design intentions, priorities and logics - are subjected to continuous reformulation.

Figure 38
Concept Rendering :
Exterior Facade Concept


40

Intent

Showcase Interior Program

In an effort to animate the street and express the building's program to the exterior, the facade scheme must maintain clear visual connections from the surrounding. By showcasing interior program, the proposal creates spectacle along its perimeter through a conscious relationship between envelope transparency and interior spatial planning.

Reveal and Conceal

While controlling transparency of the facade relative to interior spaces, opaque elements are to be integrated to conceal junctions. These undesirable join conditions are to veiled from the exterior, maintaining a streamlined fluid expression echoing the building's parti concept.

Ephemerality

The facade scheme responds to natural daylighting patterns to create varying degrees of shadow throughout the day. The envelope is to express the opposite effect during night hours, becoming a beacon of light and shadow along the Harbourfront corridor.

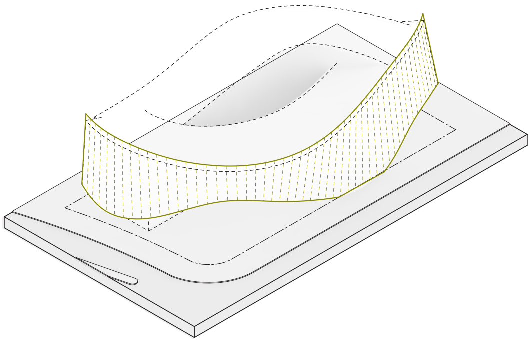
Undulation and Texture

To further engage the street and distinguish the form from its immediate context, the facade scheme will undulate to create overhangs and reveals serving as architectural elements at the interior. Levels of depth along the building envelope also serve to create variation and shadow lines further emphasizing the building's fluid language.

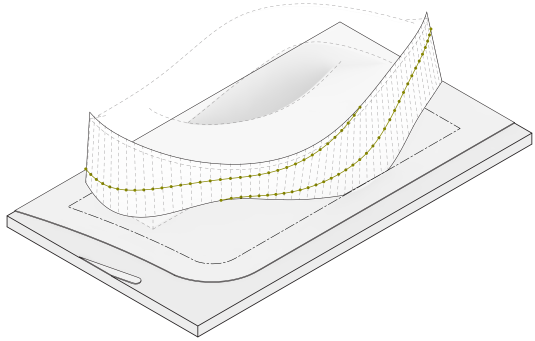
Logic

The facade scheme logic begins with the extraction, offset and division of massing surfaces. Division curves are evaluated at points derived from a linear equation, creating two subdivisions controlled by length, height and curvature amplitude. Points along each division curve are successively translated toward the envelope base plane, creating progressive projections at opposite extents of the facade. Curves interpolated from these points become the regulating lines of the facade division. Resultant surfaces are then subdivided relative to the interior structural scheme to create planar panels and mullions. A sub-notation is introduced to generate variations in shading and veiling strategies relative to the output surfaces of the facade logic.

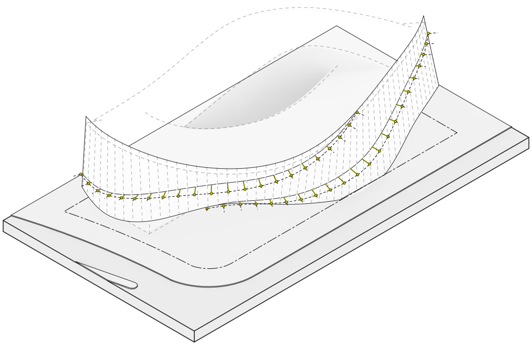
Figure 74
Facade Geometric Logic



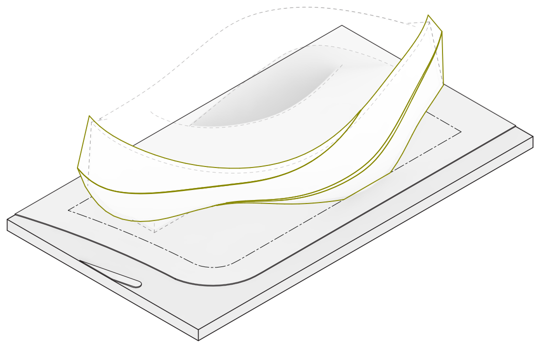
74a: Extract & Divide [Massing]



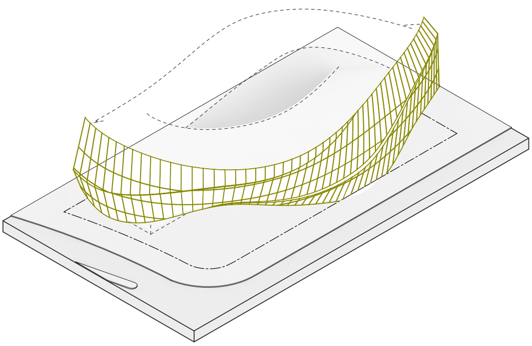
74b: Evaluate Divisions



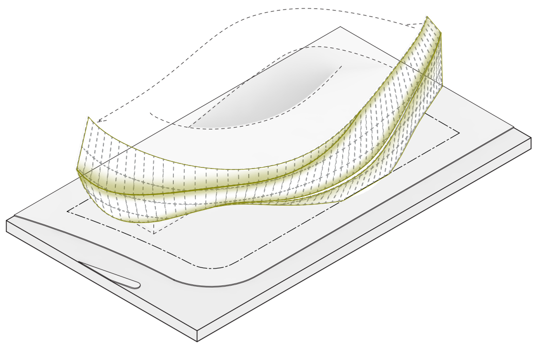
74c: Translate and Project



74d: Interpolate Regulating Curves



74e: Panelize [Structure]



74f: Veil and Shade

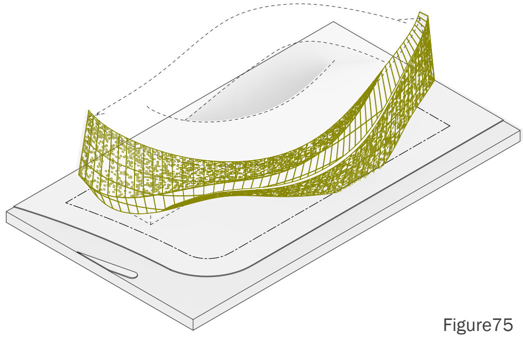


Figure75
Facade Scheme A
Gradiential Frit - Projection Value 0

Iteration & Evaluation

The resultant facade scheme iterations are created and evaluated on their divisional proportions, degree of depth, street presence, porosity and interior spatial implications. The logic is developed to strictly yield a tri-panel envelope. The panels divisional extents, orientation, projection, shading distribution, and mullion spacing are controlled through the parametric definition, combining to produce a wide array of potential variants.

Each facade scheme is also evaluated on resultant grade conditions, opacity and relativity to interior floor slab elevations and program. In addition to the manipulation of surface divisions and projections, a sub-definition allows for the iteration of facade shading schemes on each panel system. These shading systems are evaluated in conjunction with the envelope geometry toward an optimal solution that satisfies all design criteria. The ability to manipulate both the surface geometry and its opacity enables a close control and of desired interior lighting and spatial conditions. Simultaneously, the facade scheme is also iterated in relation to contextual sight lines, demanding the designer engage in a rigorous process of prioritization and selection .

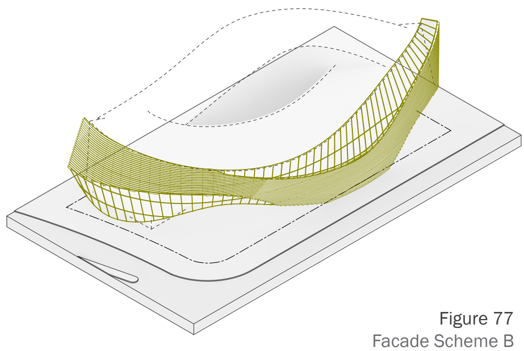


Figure 77
Facade Scheme B
Horizontal Louver - Negative Projection

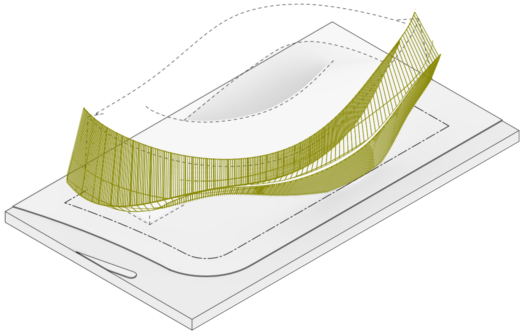


Figure 79
Facade Scheme C
Vertical Louver - Positive Projection

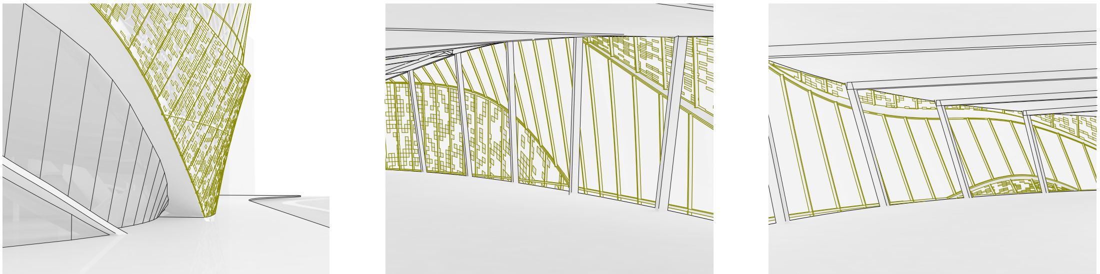


Figure 76
Facade Scheme A
Spatial Evaluations

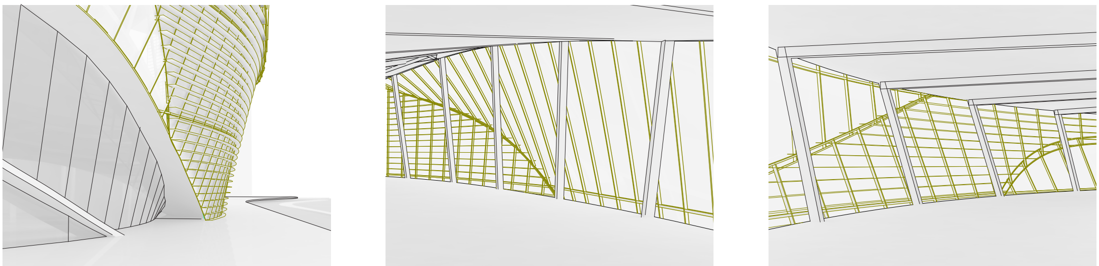


Figure 78
Facade Scheme B
Spatial Evaluations

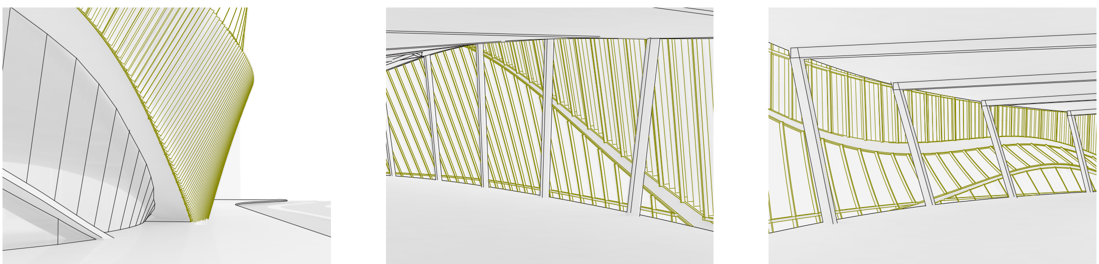


Figure 80
Facade Scheme C
Spatial Evaluations

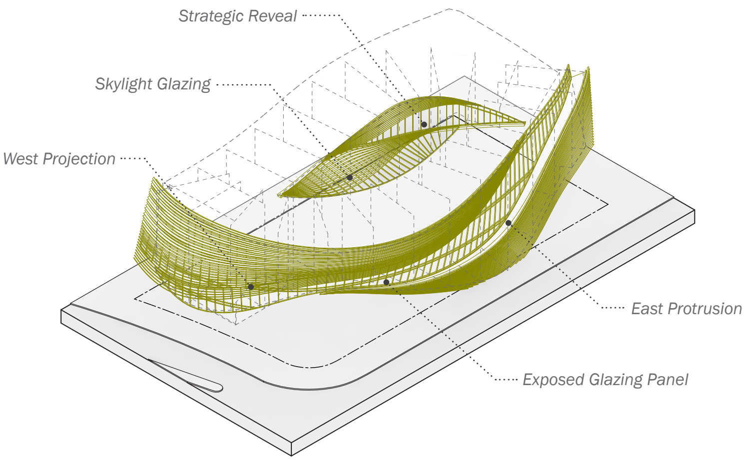


Figure 81
Developed Facade Scheme

Selection

The proposed facade scheme is bifurcated by an unobstructed band of vision glazing spanning across all upper floors of the building to reveal an extensive swath of interior program spaces. A louvered shading system negotiates tapering panel geometries by converging at each apex, yielding a gradiental transparency as louvers merge or diverge along the frontage. The facade also protrudes in opposing directions diverging from the central panel to create view points to the context at open collaborative areas and additional texture to the street face.

Conclusions

The facade design demonstrates the challenges and repercussions involved in anticipating the required flexibility and rigidity of a parametric logic. The facade scheme introduces an interesting paradox in that the geometric logic provided a wide range of possible variants allowing for the rapid iteration of the design within a very strict field of variation. The logic is rooted on a subdivision of the facade into three distinct panels. While a wide array of parameters are capable of generating an infinite list of sampling, the inherent tri-sectional division remains present throughout. Early design iterations featured modest projections - thin bands of cladding spanning across a curvilinear, yet monotonous surface. Through an extensive qualitative evaluation process, it was determined the facade required additional variability and depth to truly engage the street. An additional operation was then integrated within the logic to allow panels to progressively offset from the base massing surface. Similar to the structural scheme, the parametric model describing the facade logic can also therefore be conceptualized as a series of sub-notations working together in a system within the larger context of the building.

05 | Conclusions

Regardless of the particular object or tool employed, virtually any design undertaking can be characterized as a non-linear process of recursive evolution. Architectural design demands the mediation of complex contextual requirements through a series of steps, void of a specific design target. Whereas in tangential fields of design inquiry the primary objective is to arrive at the most functionally appropriate form, architectural design is open-ended and uncertain. This ambiguity can be credited as the reason why computational strategies are employed as a means of design justification, optimization and economization in contemporary architectural discourse. In an objective-based discipline unbound by rigid expressive or stylistic regulations, the digital architect is tasked with applying tools rooted in mathematics - a discipline founded on abstract rules with no particular objectives.

The parametric designer must occupy the gap between quantitative value and qualitative reasoning, imparting expressive, experiential and architectural knowledge upon the computational model. Nearly a century ago, Le Corbusier refers to this interaction in explanations of his engineer's aesthetic, "the engineering therefore has his own aesthetic, for he must, in making his calculations, qualify some of the terms of his equation; and it is here that taste intervenes." (Corbusier, 1923) He continues, "now, in handling a mathematical problem, a man is regarding it from a purely abstract point of view, and in such a state, his taste must follow a sure and certain path." (1923) Whereas Le Corbusier's sentiments stem from rapid changes instigated by industrialization and manufacturing processes, computational design strategies once again demand the architect straddle both realms of quantitative objectivity and qualitative subjectivity as the efficiency of a computational function as a formal strategy has to be evaluated by architectural as opposed to numerical criteria.

Computational design strategies, and parametric design in particular have therefore instigated a significant shift in the architect's traditional role and working method. Through an analysis of the parametric processes behind the massing, structure, stairs and facade of the Toronto MediaHub proposal, the impacts of such tools can be categorized under three distinct, yet closely interrelated, and in some cases overlapping concepts; notational networks, discreteness and indetermination, and recursiveness and levels of iteration.

Notational Networks

In a parametric method, the architect is tasked not only with the design of the artifact, but also the system of inter-connectivities regulating its organization. Whereas the modernist's detail was based on negotiating tolerances between pre-manufactured components, the parametric architect's details are based on the management and organization of information. The final building product is not the only design goal, the work of design occurs in the formulation of a computational system capable of revealing unanticipated formal outcomes. The work of design has therefore shifted to a higher level of abstraction - the architect is now responsible for the curation of a notational system toward a speculative design intent.

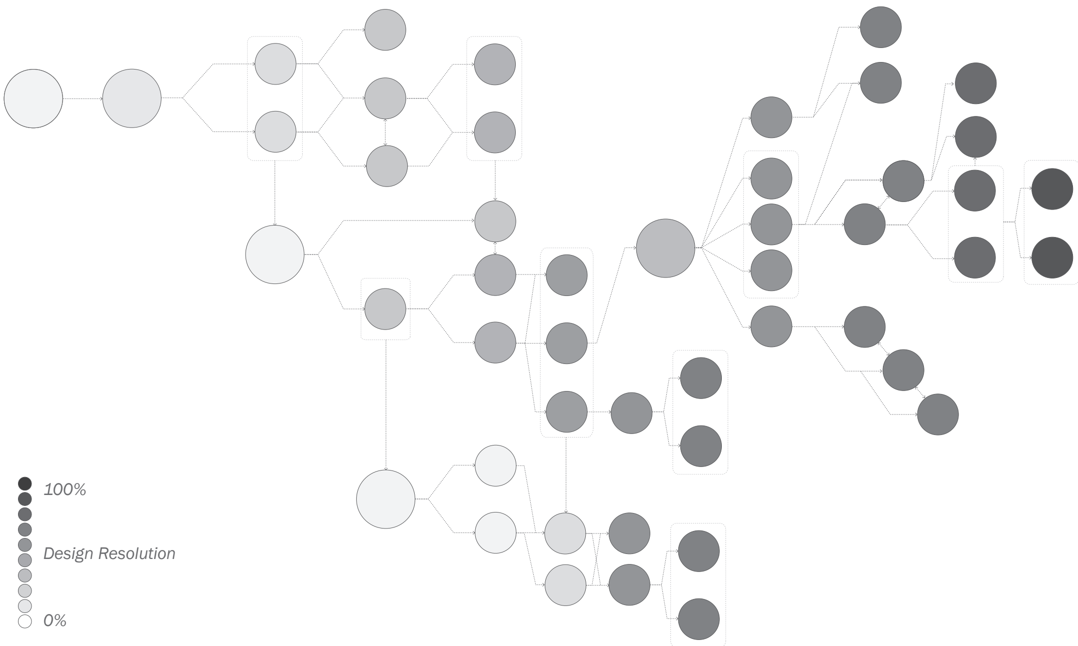
Abstraction in this context refers to the systematic development of a general solution for a given design task, suitable to all criteria. In a parametric process, the designer must distill the infinite complexity of the project to a level where it's organizational logic can be described with manageable effort. (Scheurer and Stehling, 2011) As such,, the parametric designer must gather data and filter such considerations into a streamlined logic, successively adding to and purging the logic system as the design progresses . Here, one must find patterns and define general cases toward making critical decisions that form the core direction of the design pursuit.

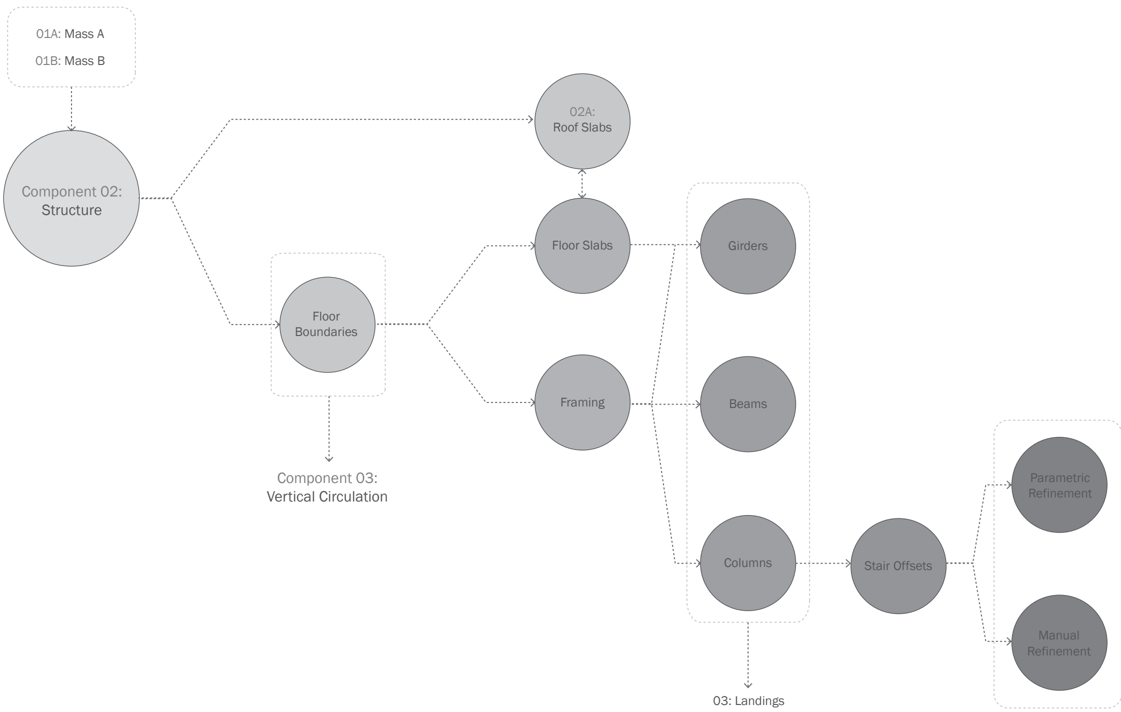
Figure 82
Schematic Diagram of a Parametric Notational Network

As the computational scheme evolves toward a higher level of design resolution, a hierarchy of notations begins to emerge - each building component is devised as a cluster of sub--notations. These sub-notations are woven into a complex arrangement of interlinked commands, each with a variable input and output. The cumulation of this sub-notational network creates a larger mechanistic system; a Turing machine comprised of a smaller Turing machines within. Some sub-notations evolve in unison, some consecutively, some overlap. It is the designer's task to organize these sub-systems, understanding where linkages must take place and where to add, edit, abandon or eliminate operations within the parametric model.

Architects have always worked with abstract processes of representation that lead to abstract processes of making. In a parametric paradigm design is a process of mediation between tool and the artifact to be produced, but also a process of exploration as a design technique.

Figure 83
Enlarged Sub-notation Cluster Diagram


100%
Design Resolution
0%


01A: Mass A
01B: Mass B
Component 02:
Structure
02A:
Roof Slabs
Floor Slabs
Floor
Boundaries
Framing
Girders
Beams
Columns
Stair Offsets
Parametric
Refinement
Manual
Refinement
Component 03:
Vertical Circulation
03: Landings

Discreteness and Indetermination

Discreteness and indetermination refers to the parametric designer's ability to establish a balance between accommodating a wide array of design variations while maintaining a specific and efficient computational logic. The cognitive challenge in devising a parametric model is to untangle the interdependencies of the project's considerations to determine a sequence of rules that are as simple as possible, while remaining flexible enough to produce an expansive field of formal possibility. Here, the designer is forced to anticipate a desired field of indetermination - exactly how flexible *should* the parametric logic be? The designer's preliminary objectives inform and formulate the strategy for the entire project while that strategy produces mutations within the specified target domain.

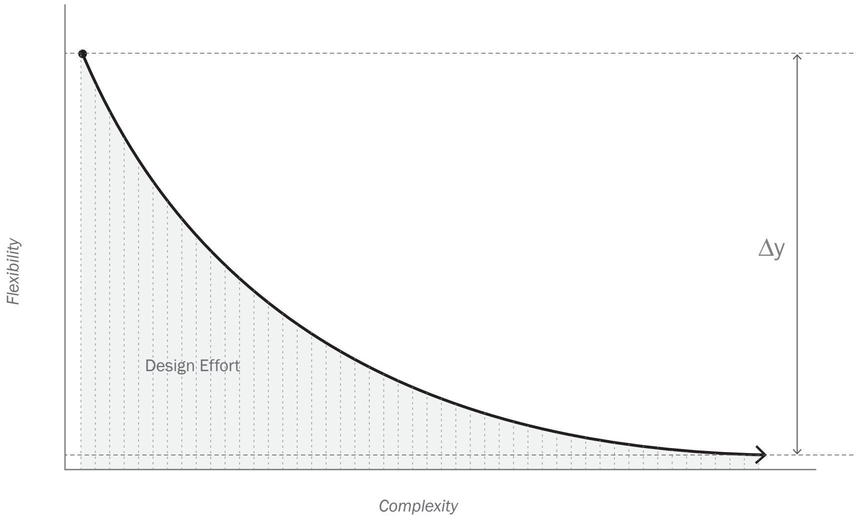
The defining logic of a parametric model must not be too rigid or too flexible, as both extremes pose negative implications to the design process. Where the logic is too flexible, a manageable level of resolution becomes nearly impossible. To account for all potential variants in a highly detailed parametric model would lay beyond the organizational capacity of the designer. Conversely, where the logic accounts for too few variable inputs, the field of potential narrows, demanding extensive iteration or reformulation of the initial logic to permit a wider range of possibility. Parametric strategies therefore demand a finer resolution of the abstract design scheme prior to developing the parametric model.

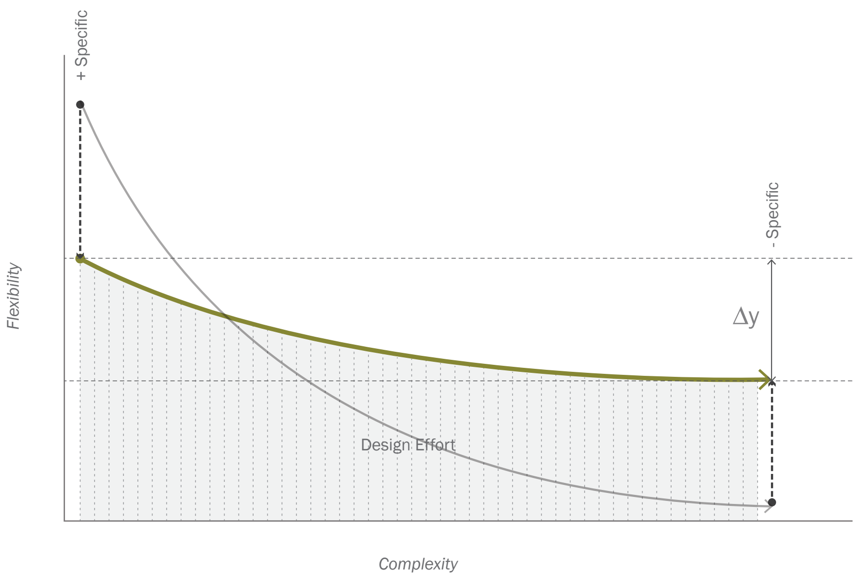
Figure 84
Flexibility and complexity in the Traditional Design Process

The parametric design process differs from that of the traditional paradigm, in that the designer's intentions must be specific - a relatively clearly defined objective must be determined prior to the formulation of a logic. Similar to traditional design strategies, the design process is evolutionary and non-linear, but commences with a more explicit understanding of the project goal. With each design commitment comes additional detail, resulting in the definition becoming much more explicit.

If one was to invert the traditional McLeamy curve, plotting both the traditional and parametric process, it becomes apparent that parametric strategies therefore have a major impact on the work of the designer. Much more specificity is required at the project's outset, however, the parametric definition permits a wider array of flexibility at its output. The area below these curves can be considered representative of the amount of design effort required. The shallower slope of the parametric design process curve, increases significantly, indicating the need for increased design effort in a parametric approach.

Figure 85
Flexibility and complexity in the Parametric Design Process


Flexibility
Δy
Design Effort
Complexity


+ Specific
- Specific
Flexibility
Δy
Design Effort
Complexity

Recursiveness and Levels of Iteration

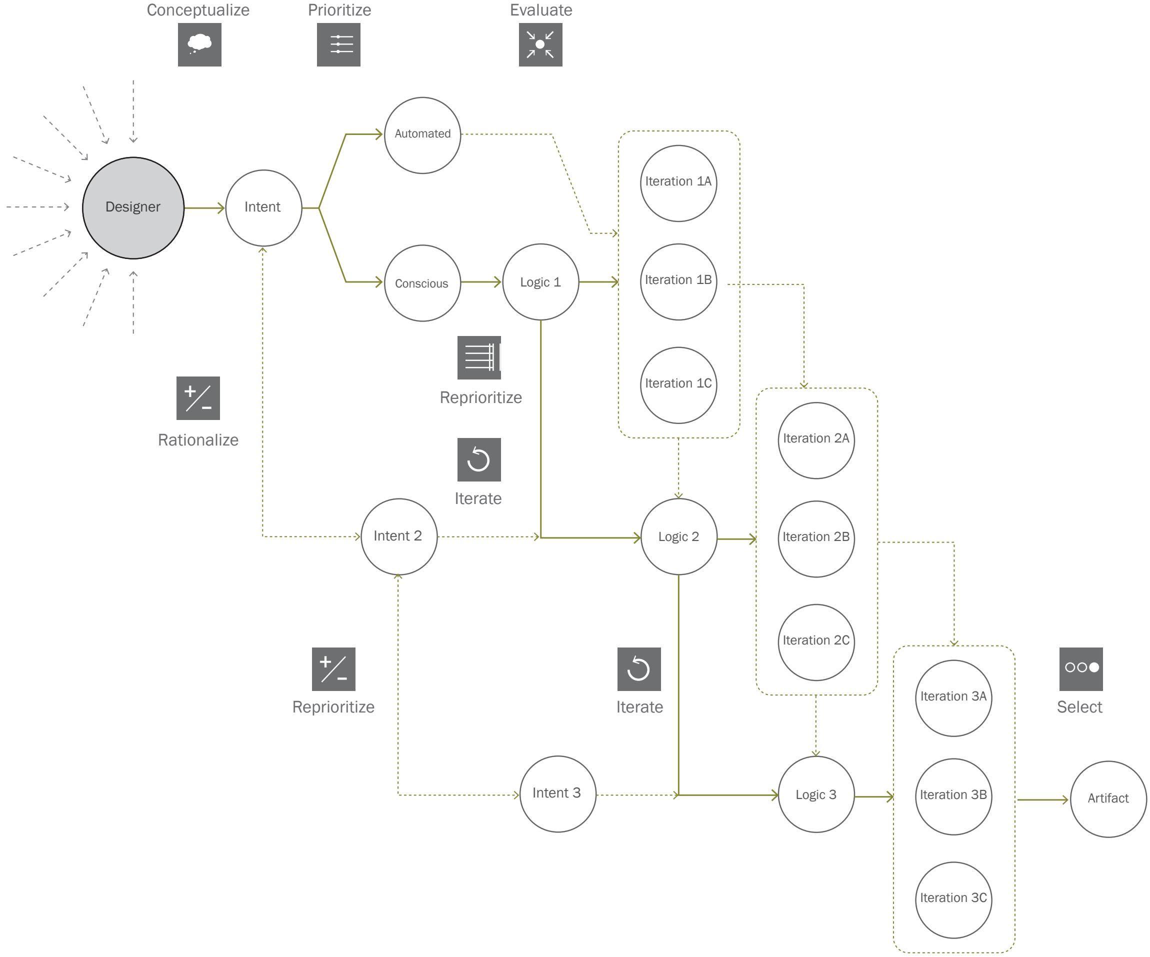
Parametric design strategies share the same non-linear recursive characteristics as that of the traditional design approach. Where parametric design differs is that it demands different levels of iteration; iterations generated by the logic, iterations of the logic and iterations of the design intentions that govern such logic. While it is clear that parametric design strategies afford the opportunity to rapidly generate iterations toward the refinement of an object, the role of the conscious designer in this case still cannot be reduced to that of a mere breeder of form. The designer simultaneously interprets, reflects and manipulates a the parametric model in a constantly reconstituting, self-reflexive process.

The efficiency and ultimate effectiveness of a parametric model lies directly in the designer's ability to edit the underlying logic. As samplings are generated, the logic itself is iterated to adjust the field of indetermination. The parametric designer responds to the generated forms and adjusts the defining logic to reveal additional variations. As the parametric model evolves to become more specific and feature a higher resolution of detail, not only are networks of sub-systems created, but previously existing operations are also revisited. Through the unveiling of patterns and relationships in the design process, it is important to add, modify or abandon concepts and gestures based on the unified system as a whole. The parametric model therefore organically evolves in a non-linear process of iteration, not dissimilar to the workflows associated with traditional design methods .

Perhaps most similar to the traditional process, is that in a parametric approach, the concept of 'intent' remains open ended and ambiguous. The vague nature of design ideation makes identifying and quantifying design intentions extremely complex as objectives constantly evolve. It is impossible to discern an accurate point form list of explicit design goals as each holds its own weight and mutates throughout the design process. The designer must continually re-prioritize the underlying reasoning guiding the parametric logic in accordance with newly discovered forms generated from such logic.

Figure 86
Levels of Iteration in a parametric process

The capacity of parametric techniques to yield new formal potentials is therefore dependent on the designer's perspective and cognitive capacity, because continuous, transformative processes ground the emergent form in qualitative cognition. (Kolarevic, 2010) The parametric designer is the curator of the parametric system, where the selection and iteration of variable outputs hinges largely on the designer's expressive sensibility.



Conceptualize
Prioritize
Evaluate
Designer
Intent
Automated
Conscious
Logic 1
Iteration 1A
Iteration 1B
Iteration 1C
Reprioritize
Rationalize
Iterate
Intent 2
Logic 2
Iteration 2A
Iteration 2B
Iteration 2C
Reprioritize
Iterate
Intent 3
Logic 3
Iteration 3A
Iteration 3B
Iteration 3C
Select
Artifact

Final Remarks

Regardless of the method or tool employed, any design tasks demands the use of heuristic knowledge - intelligence acquired over years of experience and exposure. Parametric strategies and related modes of computational design are often criticized to be emotionless form generators, simply either automating redundant tasks or deriving form from arbitrary performance objectives. In reality, the parametric process demands a high level qualitative input throughout all facets of the design process. The role of the sentient decision maker still equally as crucial in a digital paradigm - the work of the designer has simply mutated in accordance with the new tools and processes that are employed. This same transformation is evident in the architecture of the digital era as well, where expression is now deeply rooted in (and emerges from) digital experimentation and human interpretation.

In parametric design, expression is derived from functional and aesthetic design intentions in combination with the technologies capable of generating solutions outside the intellectual capacity of the designer. In both the traditional and parametric design approach, the designer is tasked with the contextualization of information – the process of collecting, deciphering, identifying and organizing data toward a particular objective. In the parametric approach, expression is the result of a synergetic relationship between the human creator and the computational tool. In architectural discourse of the digital era, expressive value stems not from arbitrary creativity or computational determinism, but from creative computation and computational creativity. (Kotnik, 2010)

The computational tool should therefore be considered a prosthetic to the architectural imagination, not a inhibitor. Fundamentally, computational design still involves a systemic series of rationalizations and commitments in pursuit of a simplified solution. The architect's role in a parametric paradigm is to mediate between the technological tool and the architectural considerations first outlined by Vitruvius centuries ago. The digital architect must entwine functional, performative and expressive considerations into an abstract description for design. As such, the traditional notion of the architect as a demiurgic designer is transforming in parallel with the topical design tools; the architect of the digital era is emerging as a controller of processes, becoming a curator of complexity.

07.1 | Appendix A: Site Analysis

Waterfront Proximity

Considering the high cooling demands required by a technology-based typology and its server infrastructure, proximity to a large body of water is an asset. Data centres often employ cooling strategies that circulate water throughout server storage spaces, thus significantly reducing mechanical cooling loads. Although this infrastructure will not be designed in granular detail, it is a key component in the feasibility of the digital library typology at the water's edge.

Downtown Location

Proximity to the downtown core is critical in the siting of the Toronto MediaHub. Access to public transit within a centralized location ensures accessibility to the public facility while limiting vehicular parking required on site. With already established well serviced connections to the downtown core and the greater city at large, the digital library becomes an accessible amenity to a broad, diverse population.

Figure 87
Site Context:
Built Form

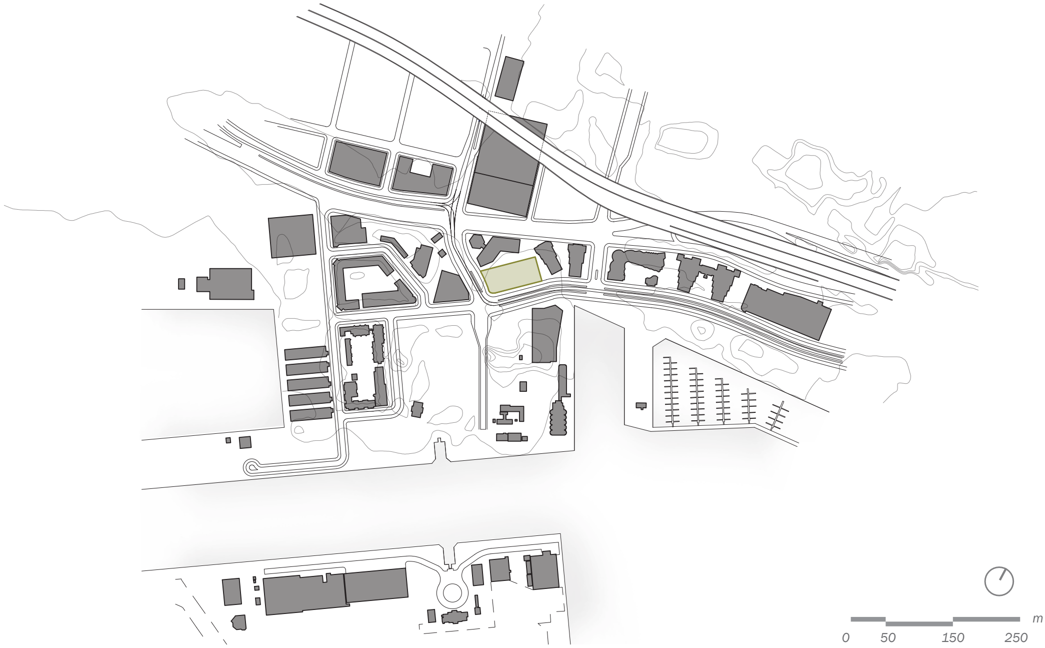
Ample Solar Exposure

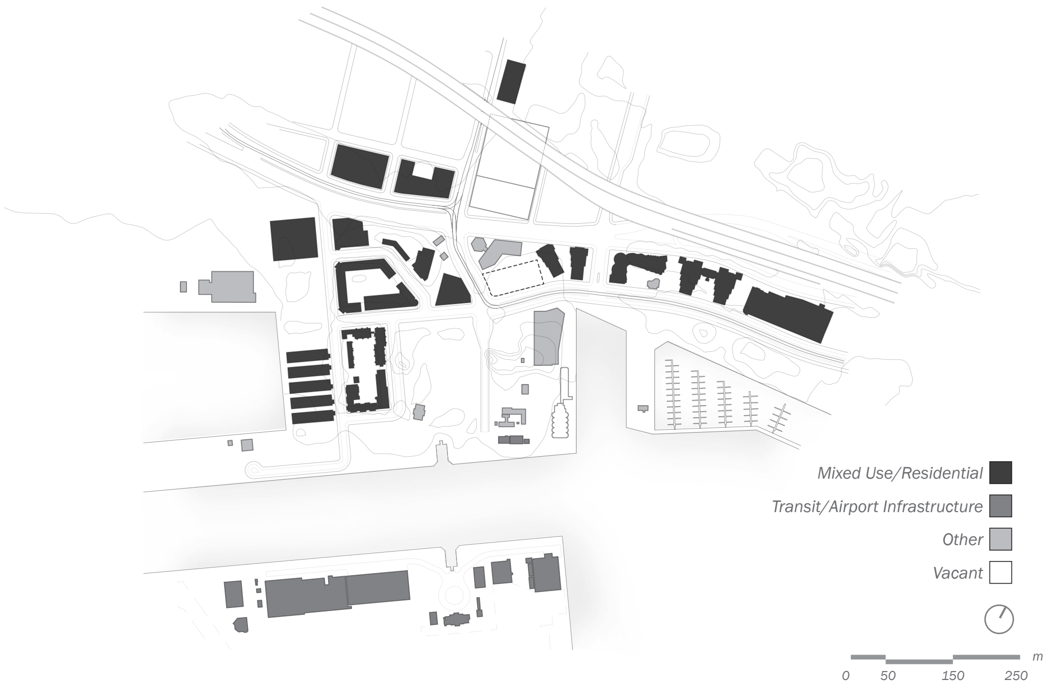
Natural light is critical to the functional and aesthetic performance of the library typology. Reading lounges, study spaces and congregation spaces are some of the many program elements that require ample illumination for their operations. While much of the building's heating will be generated by the heat exchange systems to adjacent server storage space, winter heat gains will supplement this strategy.

Currently Underutilized

A major component of the design proposal is to demonstrate how through a new interpretation of an antiquated typology can positively contribute to its adjacent community through its physical form. It is critical that the project undertake a currently inefficient, underutilized or vacant urban plot to demonstrate how a close consideration of context can transform its surrounding through carefully articulated architectural gestures.

Figure 88
Site Context:
Surrounding Typologies


m
0
50
150
250


Mixed Use/Residential
Transit/Airport Infrastructure
Other
Vacant
m
0
50
150
250

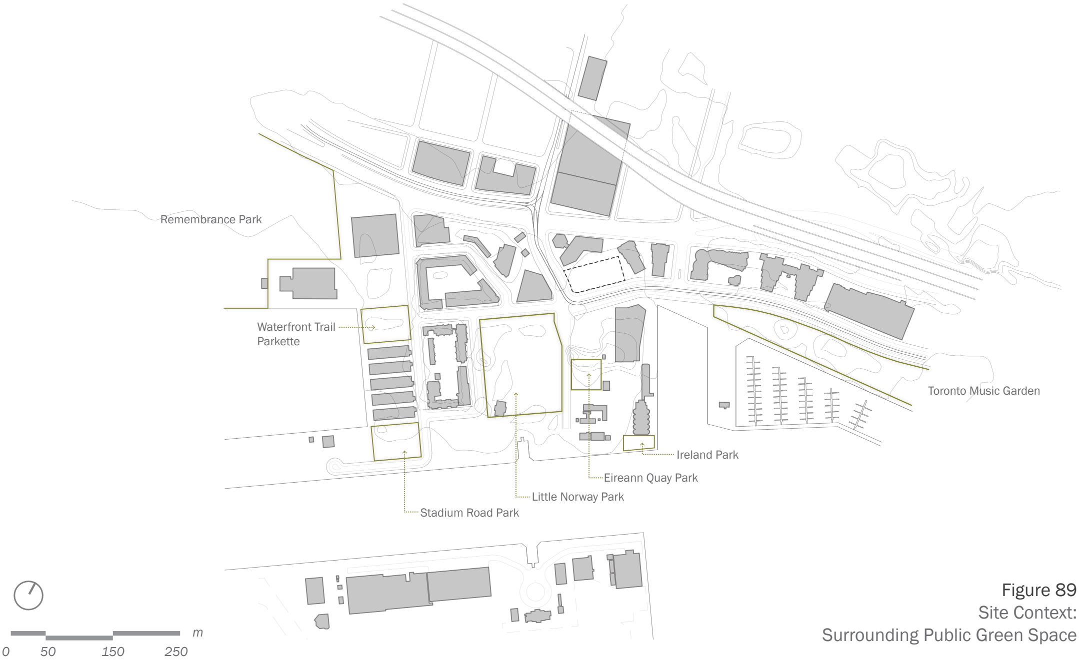


Figure 89
Site Context:
Surrounding Public Green Space

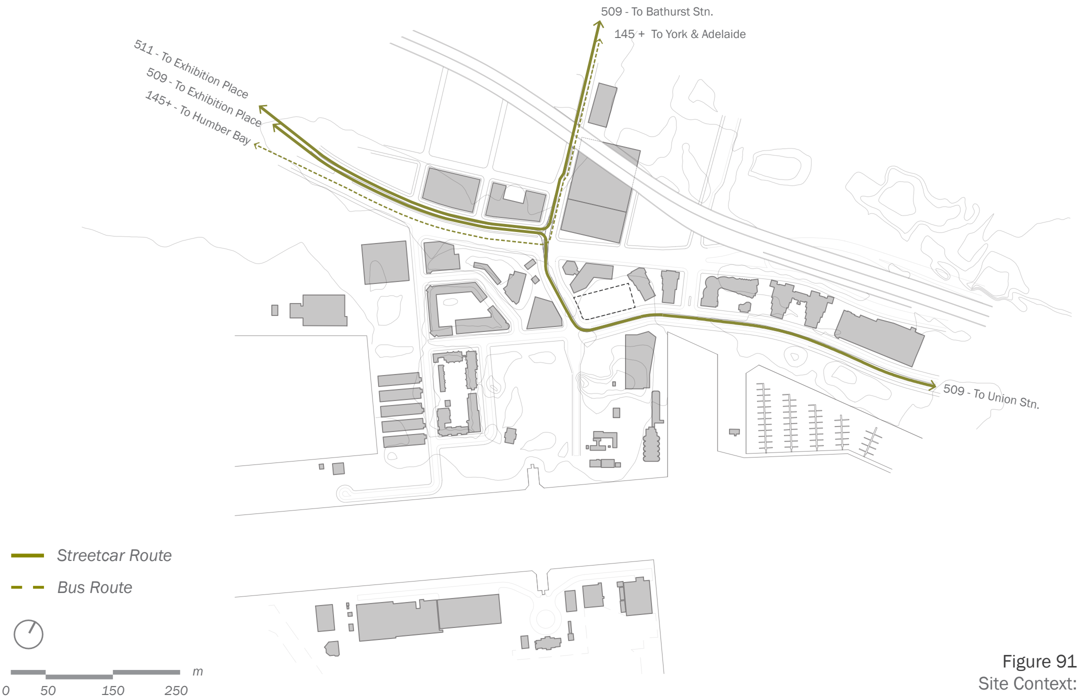


Figure 91
Site Context:
Public Transportation Access

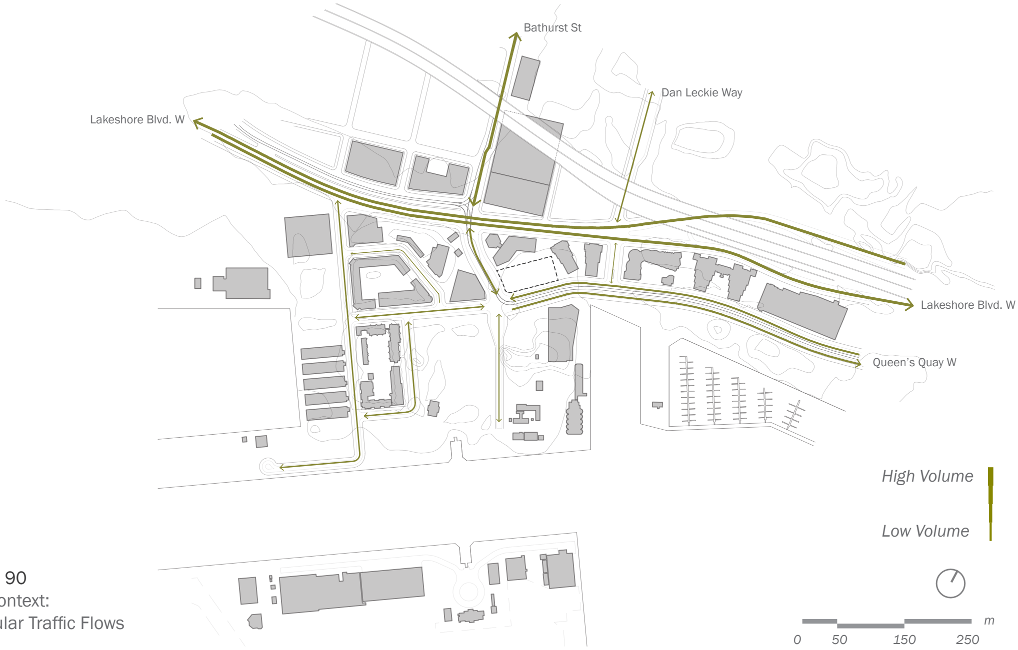


Figure 90
Site Context:
Vehicular Traffic Flows

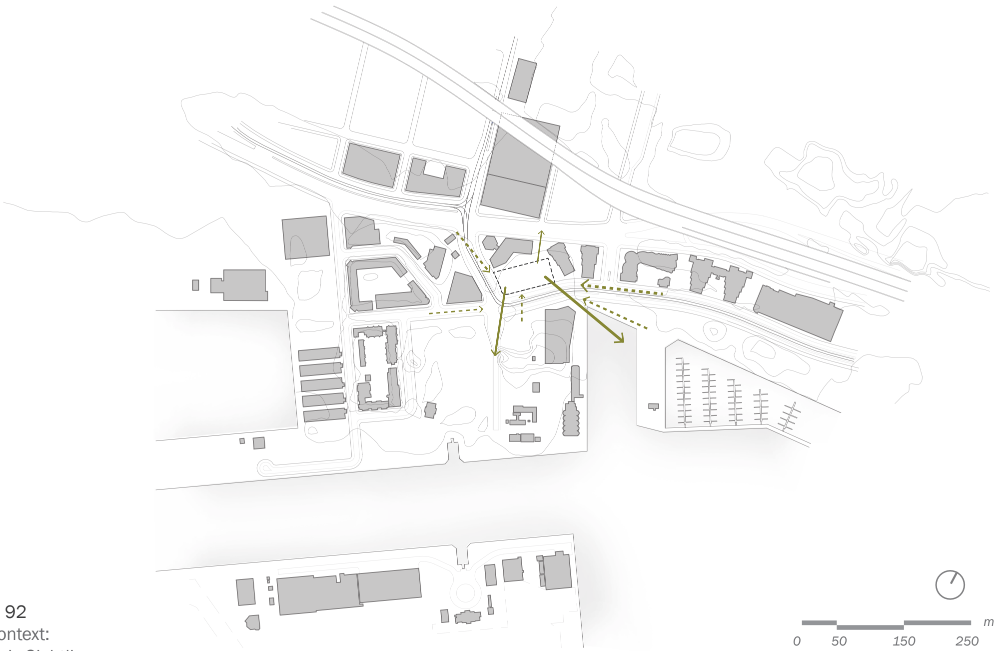
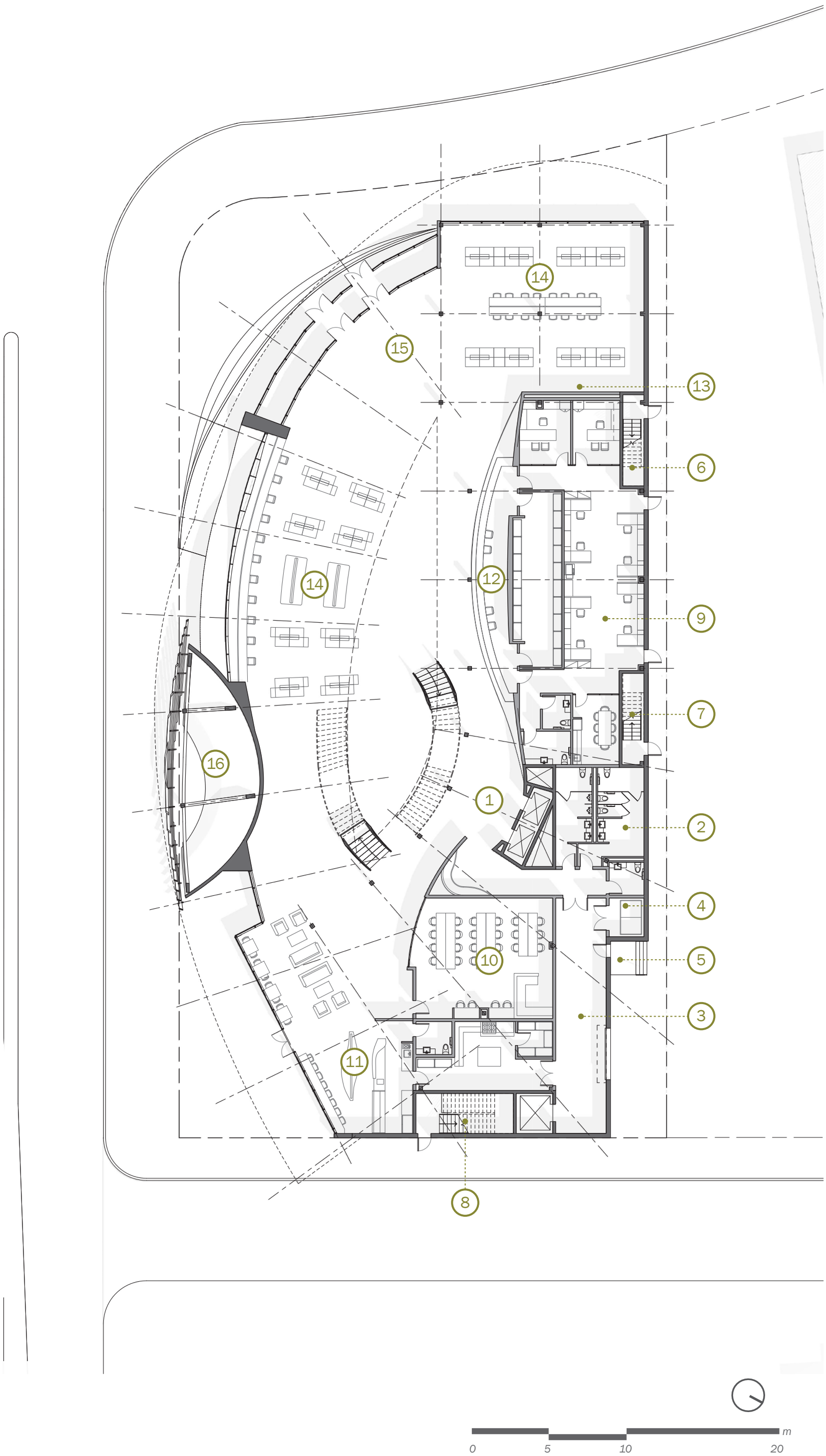


Figure 92
Site Context:
Strategic Sightlines

07.2 | Appendix B: Orthographic Drawings

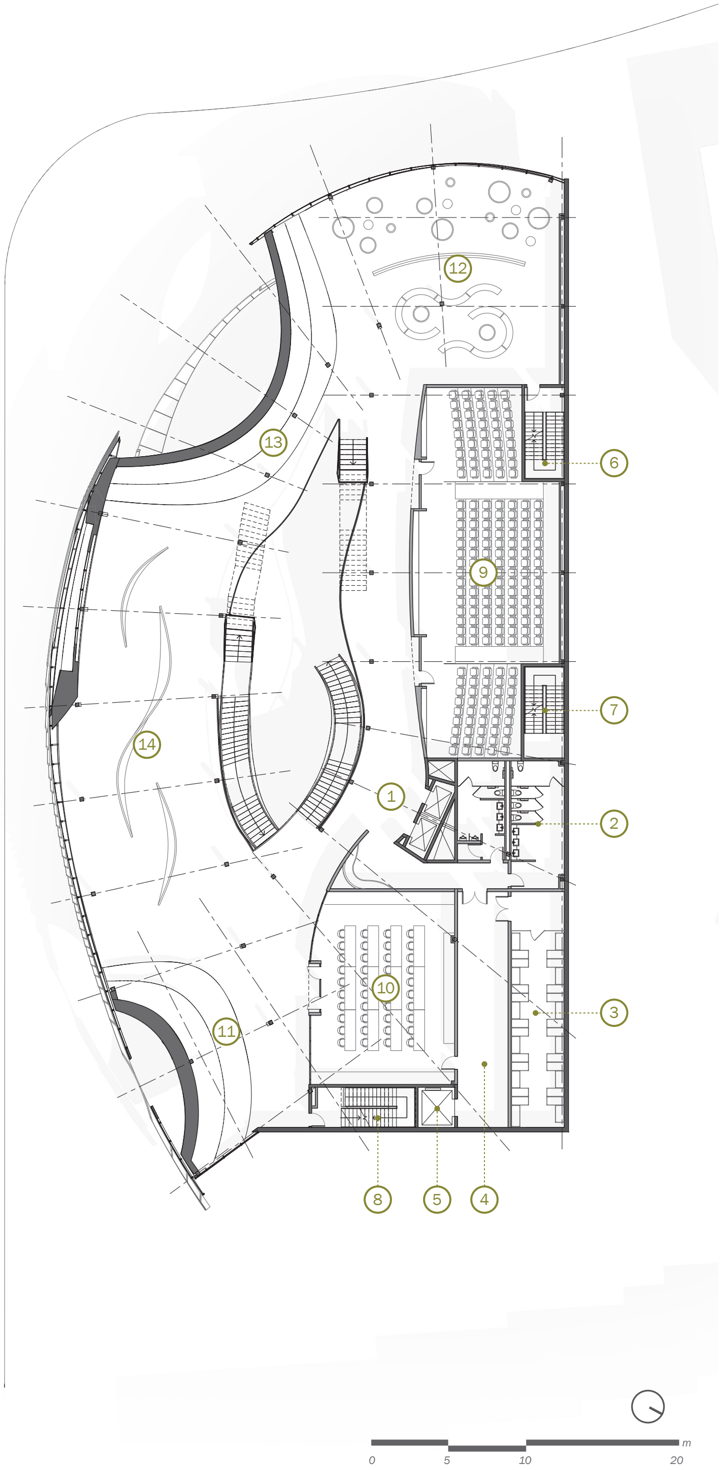


1 *Elevator Waiting*
2 *Washroom Core*
3 *Receiving Area*
4 *Garbage/Recycling*
5 *Rear Entry*

6 *Egress Stair A*
7 *Egress Stair B*
8 *Egress Stair C*

9 *Staff & Support Spaces*
10 *Community Services*
11 *Cafe*
12 *Welcome Desk*
13 *Media Wall*
14 *Seating Area*
15 *Main Entry*
16 *Promotional Display*

Figure 93
Floor Plan: Ground Level



1 *Elevator Waiting*
2 *Washroom Core*
3 *Server Space*
4 *Building Storage*
5 *Freight Elevator*

6 *Egress Stair A*
7 *Egress Stair B*
8 *Egress Stair C*

9 *Lecture Hall*
10 *Digital Innovation Hub*
11 *Seating Area*
12 *Learning Lab*
13 *Seating Area*
14 *Exhibition Space*

Figure 94
Floor Plan: Level Two

1. Elevator Waiting
2. Washroom Core
3. Server Space
4. Building Storage
5. Freight Elevator

6. Egress Stair A
7. Egress Stair B
8. Egress Stair C

9. Meeting Rooms
10. GeoSpatial Data Centre
11. Digital Archives
12. Collaborative Work Space
13. Help Desk/Seating Area
14. Open Browsing

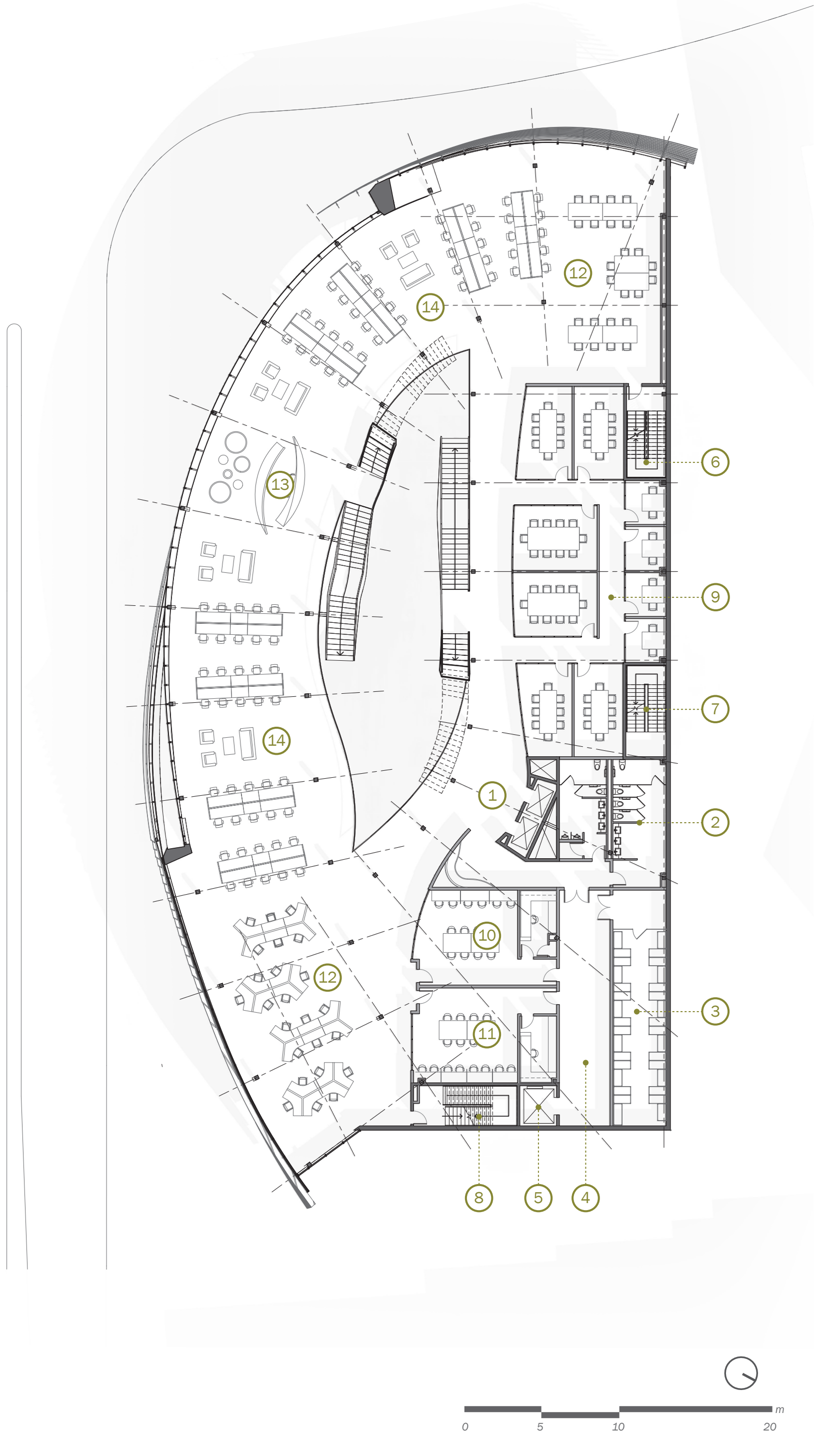


Figure 95
Floor Plan: Level Three

1. Elevator Waiting
2. Washroom Core
3. Server Space
4. Loading/Garbage
5. Rear Entry

6. Egress Stair A
7. Egress Stair B
8. Egress Stair C

9. Classrooms
10. Creative Media Lab
11. Music & Audio Lab
12. Amphitheater
13. Help Desk/Seating Area
14. Open Workstations
15. Collaborative Work Space

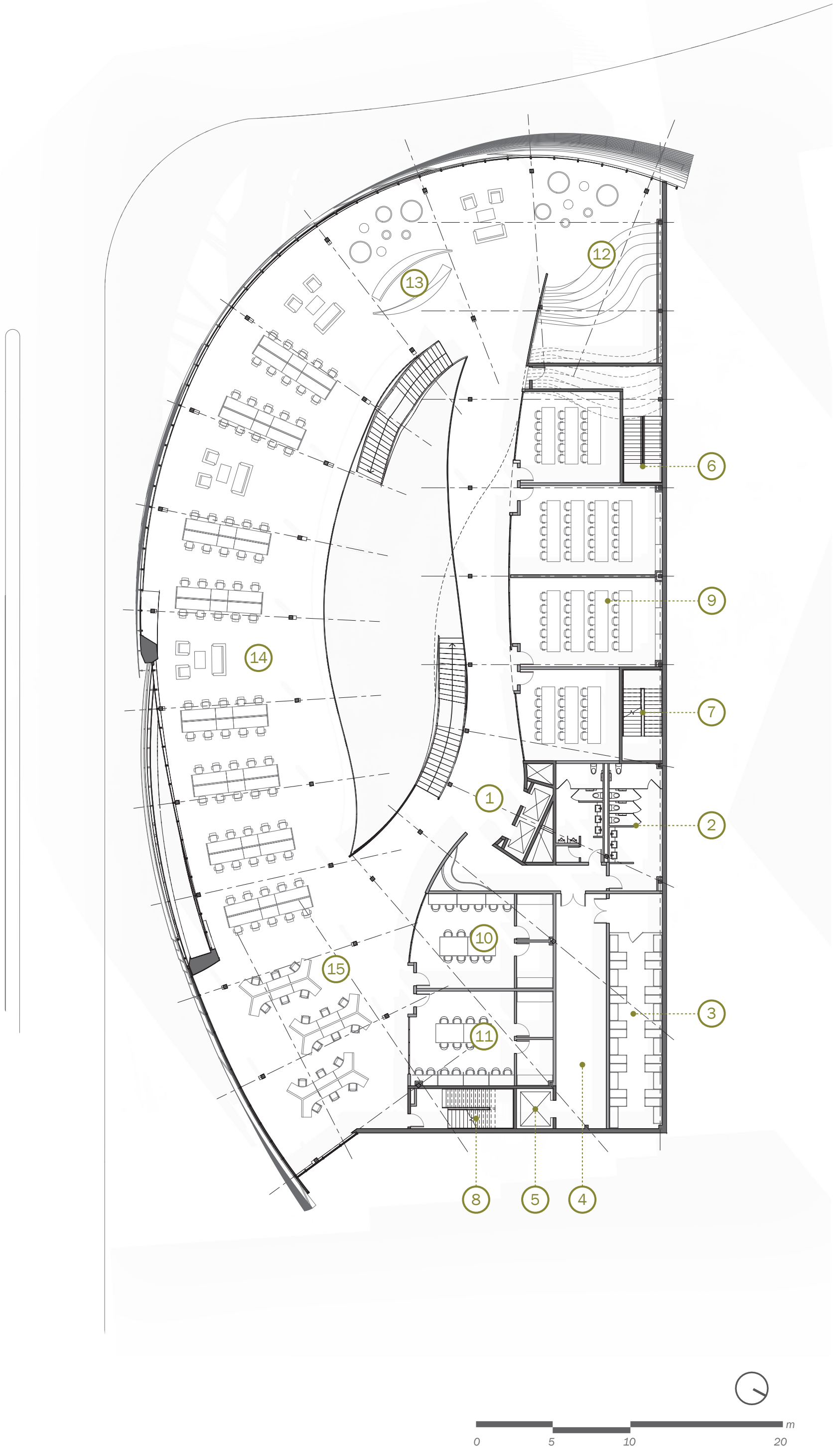


Figure 96
Floor Plan: Level Four

1. *Elevator Waiting*
2. *Washroom Core*
3. *Server Space*
4. *Building Storage*
5. *Electrical/Telecom*

6. *Egress Stair A*
7. *Egress Stair B*
8. *Egress Stair C*

9. *Study/Meeting Rooms*
10. *Living Room*
11. *Multipurpose/Event Space*
12. *Roof Terrace*

Figure 97
Floor Plan: Level Five

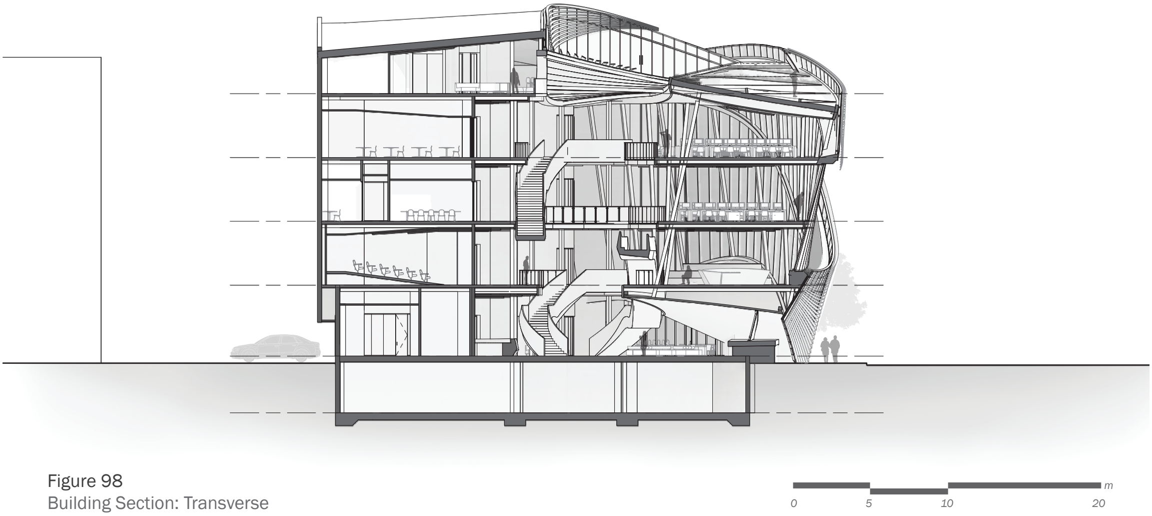


Figure 98
Building Section: Transverse

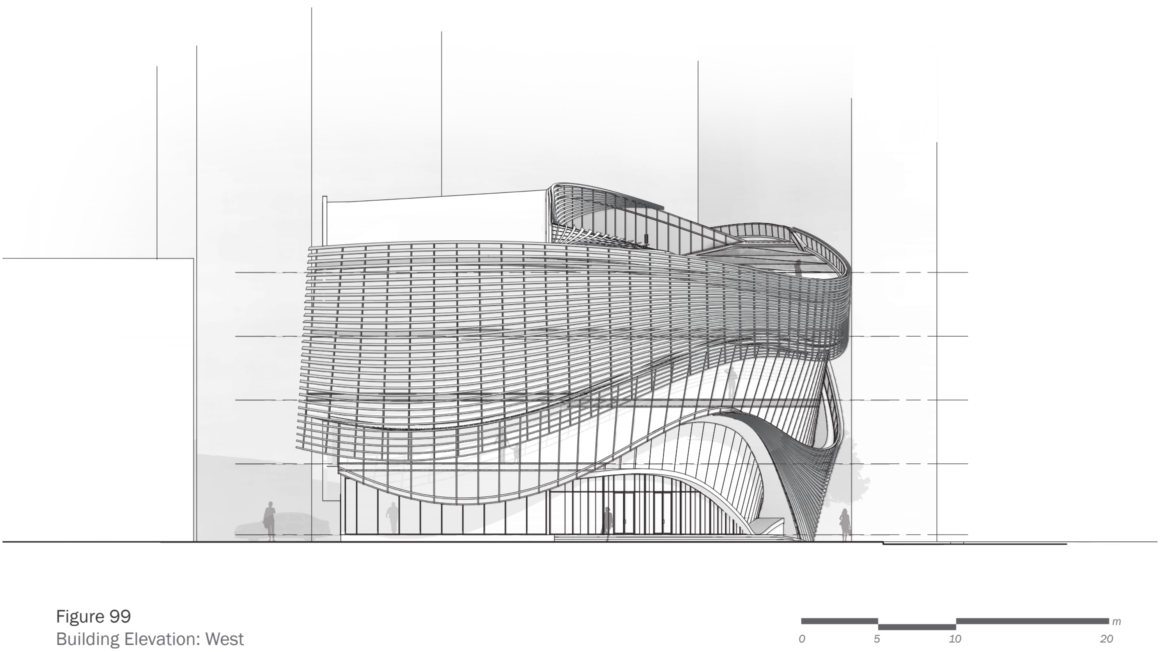
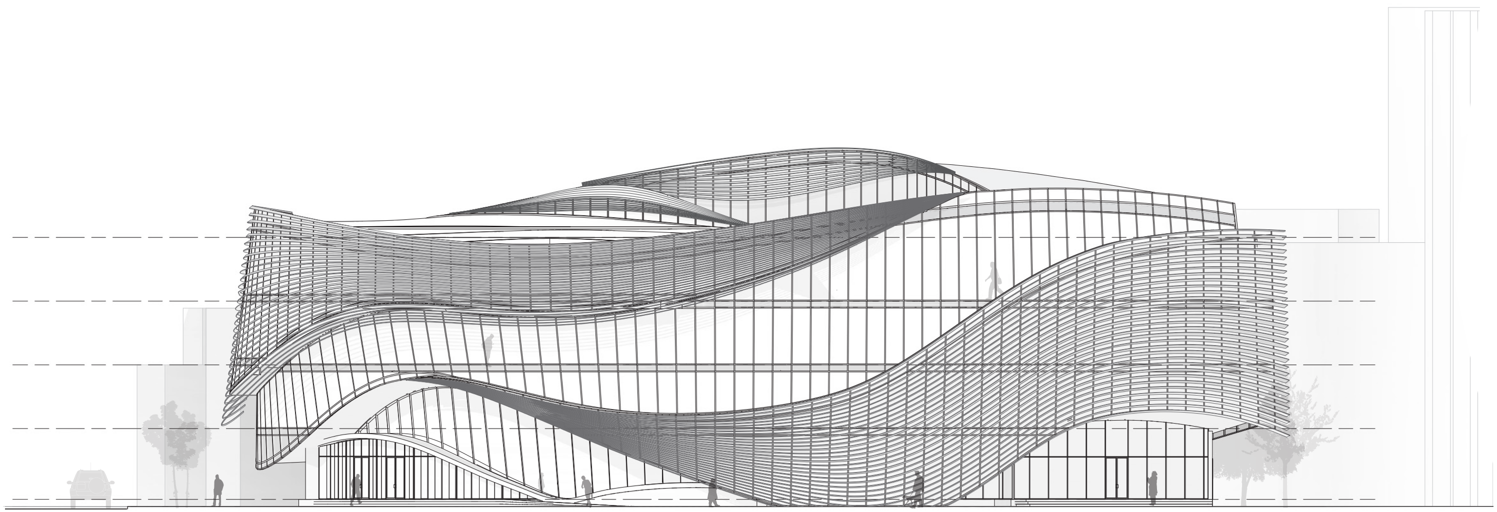


Figure 99
Building Elevation: West



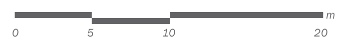


Figure 100
Building Elevation: South

07.3 | Appendix C: Concept Renderings

Figure 101
Concept Rendering:
Ground Level Primary Entry

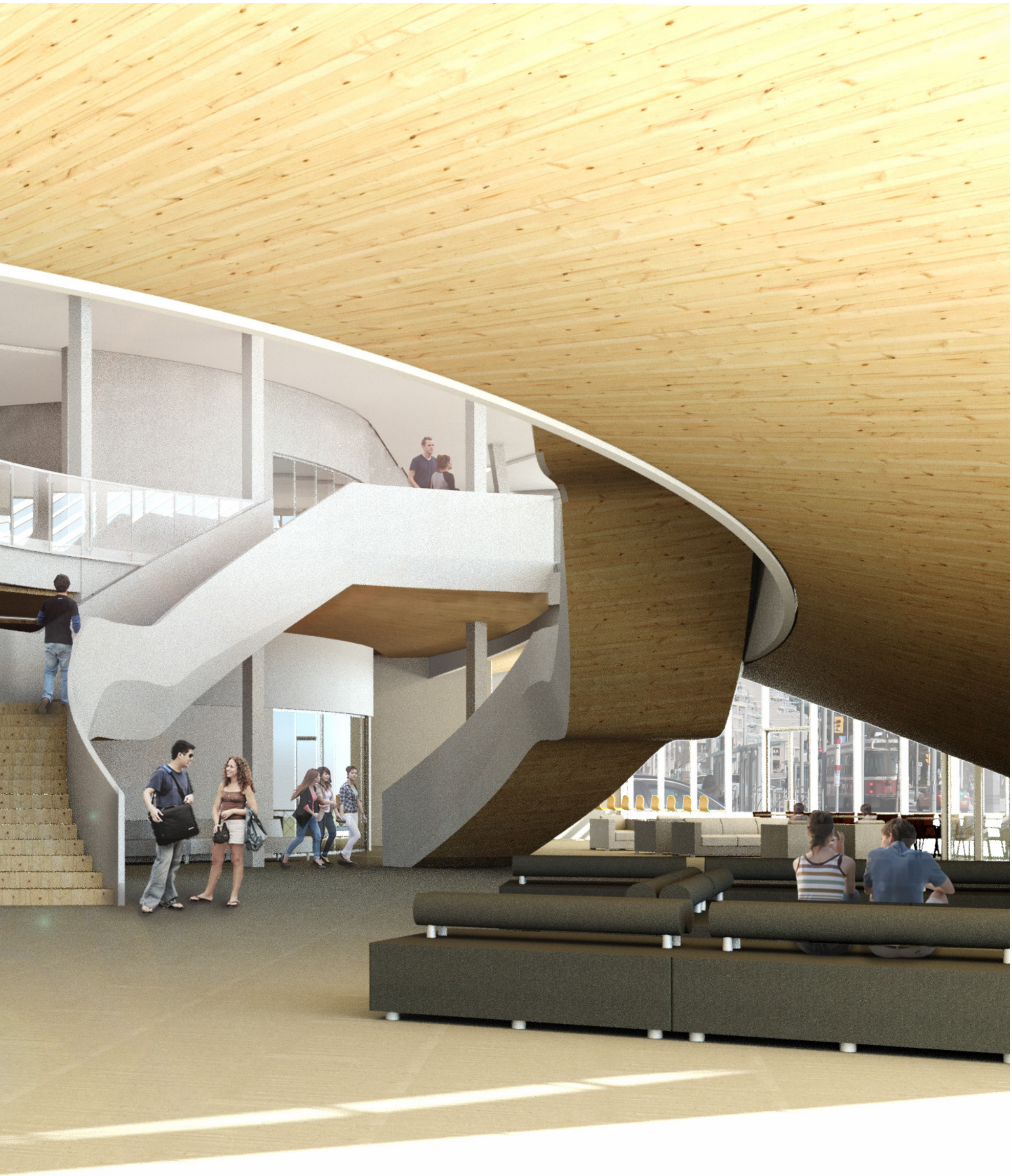


Figure 102
Concept Rendering:
Ground Level Atrium Reception

Figure 103
Concept Rendering:
Level Two Learning Lab


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Figure 104
Concept Rendering:
Level Two Exhibition Space

Figure 105
Concept Rendering:
Level Three Seating Area

Figure 106
Concept Rendering:
Level Three Corridor

Figure 107
Concept Rendering:
Level Four Collaboration Space

Figure 108
Concept Rendering:
Level Four Amphitheater Seating

Figure 109
Concept Rendering:
Level Five Living Room

Figure 110
Concept Rendering:
Level Five Roof Terrace

07.4 | Appendix D: Massing Iteration Model

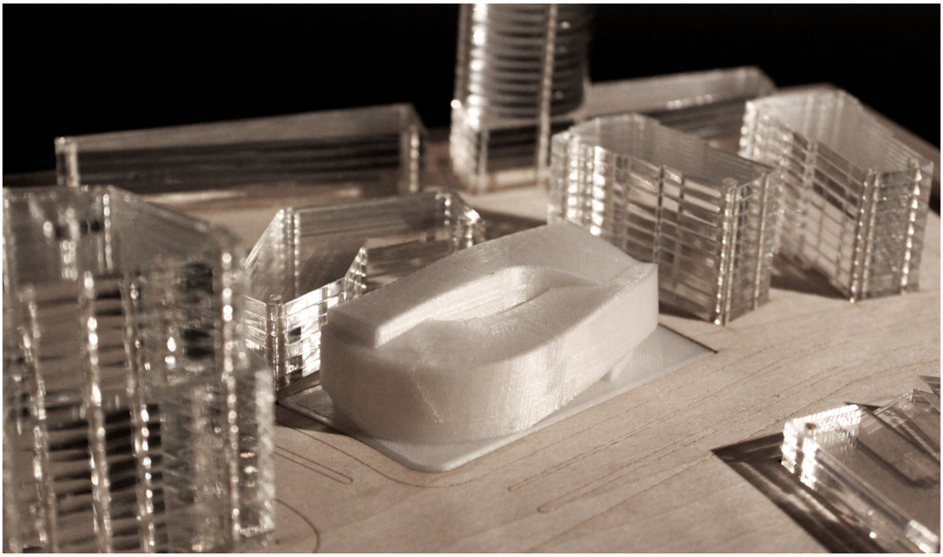


Figure 111
Massing Model: Scheme A

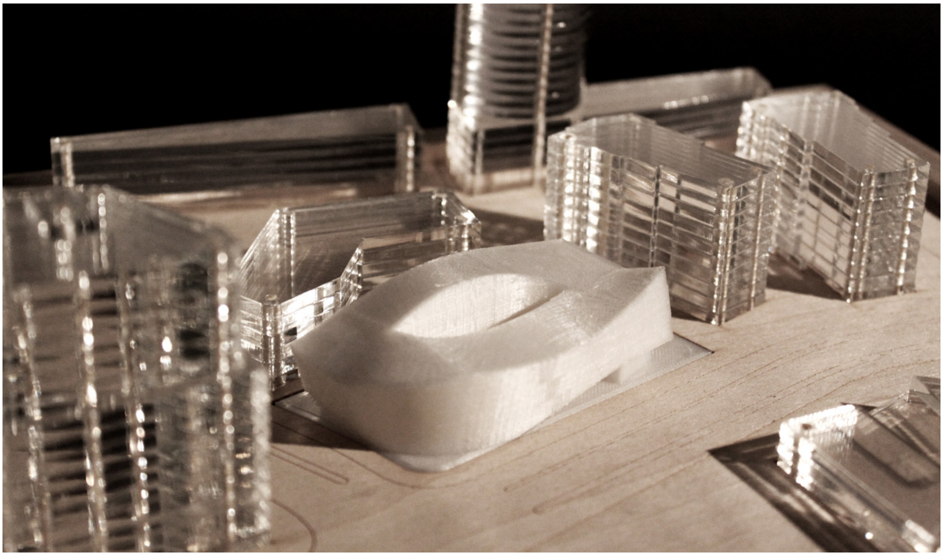


Figure 113
Massing Model: Scheme C

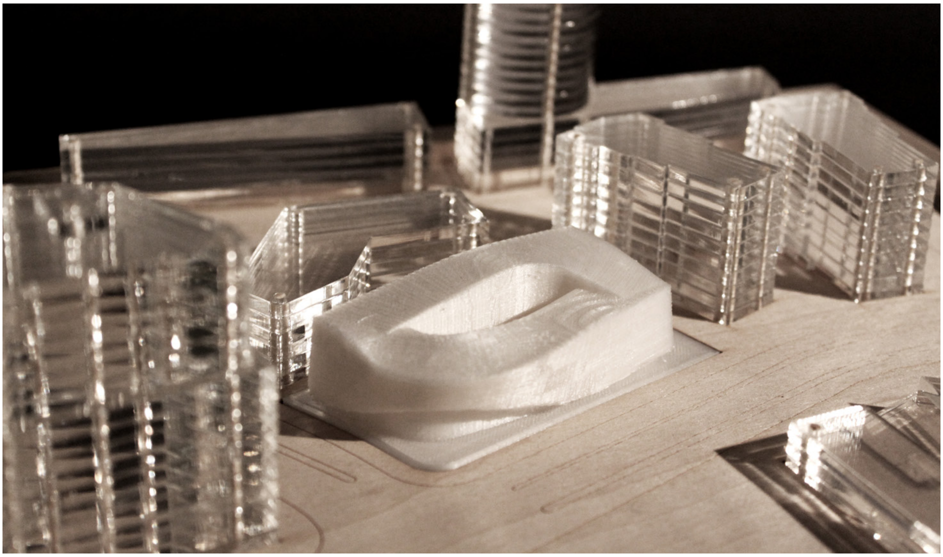


Figure 112
Massing Model: Scheme B

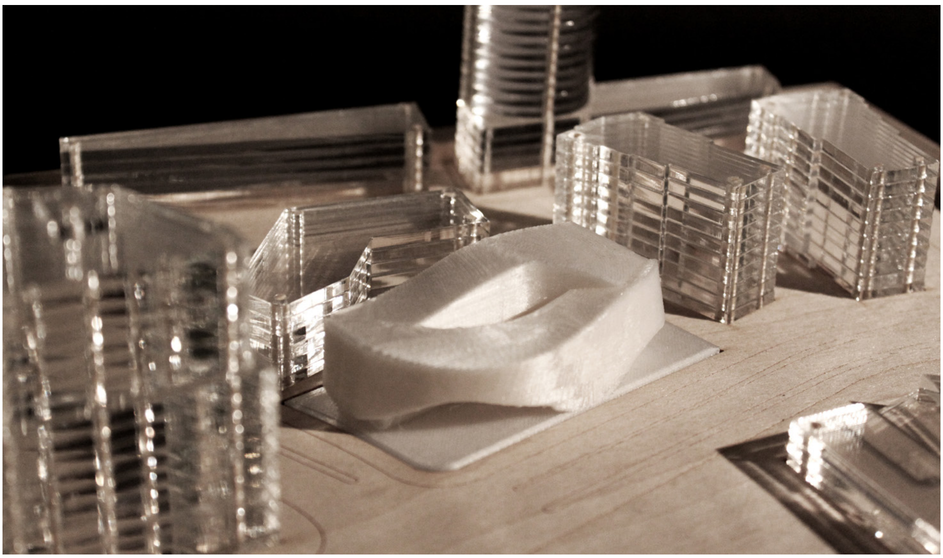


Figure 114
Massing Model: Developed Scheme

07.5 | Appendix E: Consolidated Grasshopper Definition

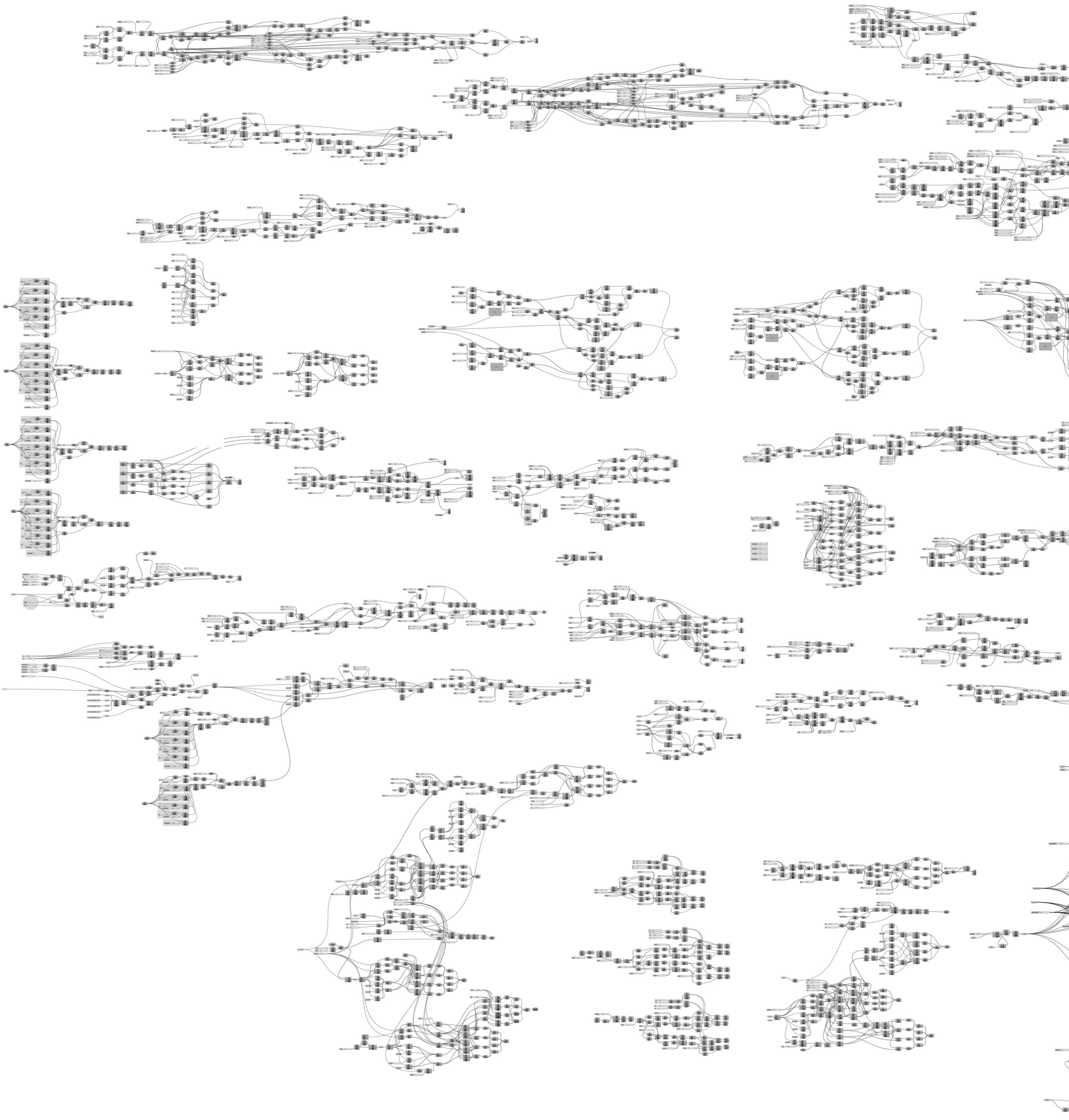
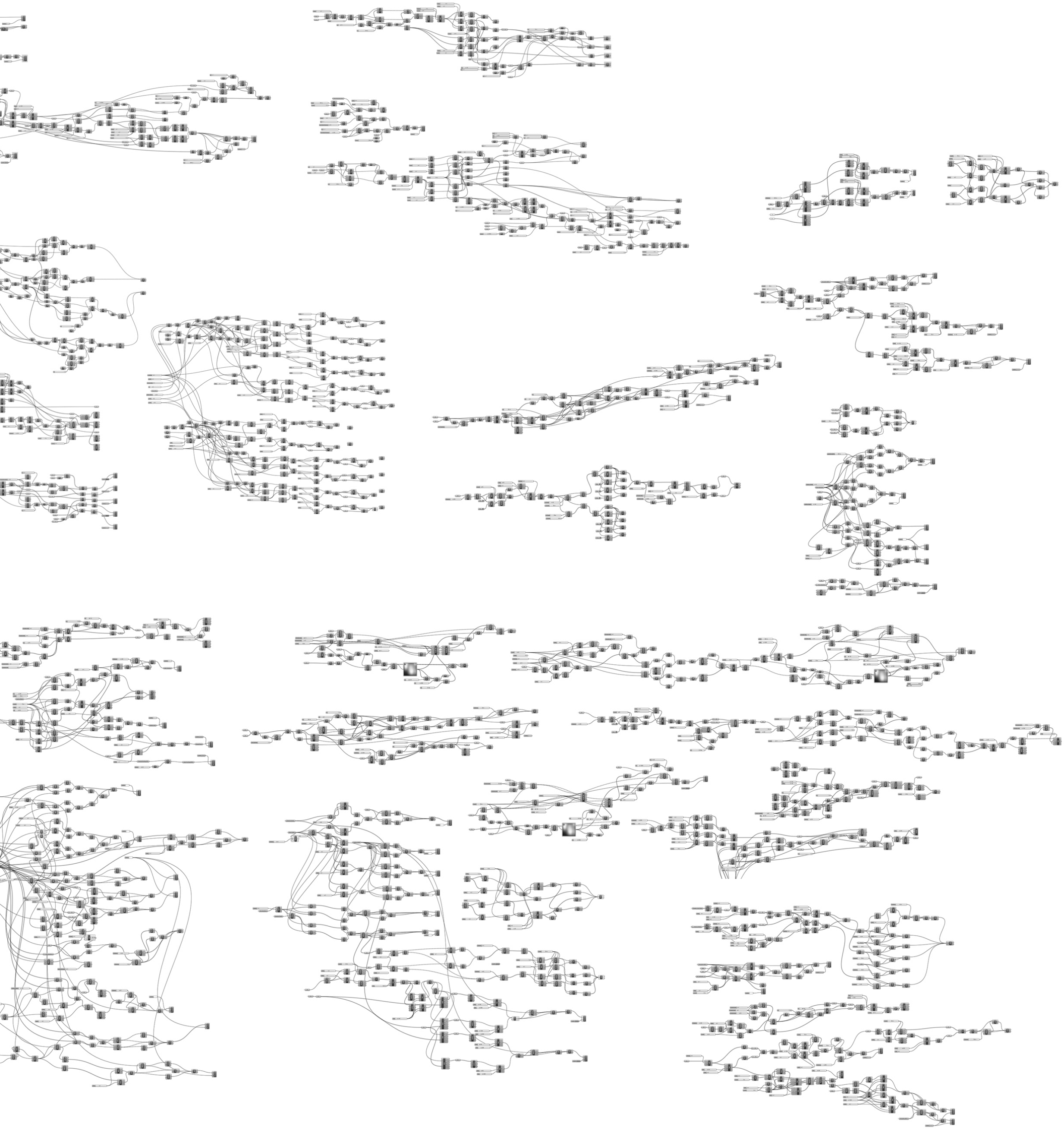


Figure 115
Final Consolidated Grasshopper Definition



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