Generative Modeling as a tool in Urban Riverfront Design; an exploration of Parametric Design in Landscape Architecture

THESIS

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ABSTRACT

Architects continuously hear about new and innovative processes to design and build the places that arise in this world, often based on “rule sets” and geometric design relationships which may or may not be revealed in the final design form. At times these hidden or “invisible” geometries become lost or forgotten during the design process and production (Stavric and Marina 2011) making it difficult, if not impossible to replicate or fully understand the system in place. In generative modeling there are certain sets of rules, also known as parameters or constraints applied to the design process and outcome. During the generative modeling process, each step in the design is documented and capable of being viewed, evaluated and altered. Currently, few if any applications of parametric design have been made in landscape settings.

This study investigates and evaluates generative modeling as a design tool in urban riverfront systems, and the design experience inherent in the process. The study methodology (1) researches the fundamental background of generative modeling through literature review (2) minimizes the variables in the design process by identifying the urban riverfront typologies and HSW standards applicable to urban riverfront design, (3) identifies an urban riverfront site to test the generative modeling design process, (4) generates parametric algorithms from the standards applicable to urban riverfront path
design (derived from the identified typologies and HSW criteria) (5) analyzes the site for attractors, detractors and ambiguous elements and (6) concludes with analysis and discussion of both the resulting urban riverfront design iterations and the generative modeling design experience.

The analysis and evaluation suggest that use of generative modeling in urban riverfront design allows for rapid production, exploration, and evaluation of various iterations for designers and clients consideration. These multiple iterations facilitate an interactive process that increases design awareness and potentially enhances and improves design outcomes.
DEDICATION

This document is dedicated to my family.
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CHAPTER 1

INTRODUCTION

Architecture and related fields have continuously sought after and experienced new and innovative processes to design and build the places that arise in this world. These processes have always required some system of mathematical thought to produce designs. Sometimes these mathematical “ordering” systems are apparent, other times they are hidden in the final work. At times these hidden or “invisible” geometries become lost or forgotten during the design process and production (Stavric and Marina 2011) making it difficult, if not impossible to replicate or fully understand the system in place.

Furthermore, a potential limitation or flaw in many design processes is that projects are designed in parts or phases, rather than a holistic manner. This can restrain the designer, and reduce the overall success of the project.

The notion of parametric and generative modeling is often connected to solving some of these dilemmas of forgotten or hidden design geometries and processes. In generative modeling there are certain sets of rules, also known as parameters or constraints applied to the design process and outcome. During the generative modeling process, each step in the design is documented and capable of being viewed and altered. Currently, much of generative modeling is being used in architecture for building design
to generate more complex forms. Currently, few if any applications of parametric design have been made in landscape settings.

The impetus of this study is to fill the gap identified in the exploration of generative modeling as applied to a specific landscape architecture type: Urban Riverfront design. In urban riverfront design, there are often numerous phases of the process, in which each phase has typological conditions that must adhere to parameters which gives consideration for health, safety, and welfare (HSW) concerns.

The purpose of this study is to investigate and evaluate generative modeling as a design tool, exploring its use in urban riverfront systems, and the “design experience” inherent in the process.

The study methodology (1) researches the fundamental background of generative modeling through literature review (2) minimizes the variables in the design process by identifying the urban riverfront typologies from award winning urban riverfront designs and identifies discrete HSW standards applicable to all urban riverfront design, (3) identifies an urban riverfront site to test the generative modeling design process, (4) generates the required parametric algorithms from the standards applicable to urban riverfront path design (derived from the identified typologies and HSW criteria) (5) analyzes the site for attractors, detractors and ambiguous elements  and in (6) concludes with analysis and evaluation of both the resulting urban riverfront designs and the generative modeling design experience.

The hypothesis of the study is that generative modeling can be an effective and useful tool to explore and evaluate multiple design scenarios, and the designer’s
experience in applying such parametric based design systems enhances the designer’s awareness and understanding of the controlling elements of the site, the design typology and relationships between all site and user criteria. These notions suggest that parametric design allows the designer to explore many more alternative solutions than traditional design processes; while in this case, assuring that each iteration meets the standards for safe access controlling the mandated aspect of design, thus allowing the designer more time to focus on the experiential and qualitative aspects of the design.

To reduce the variables in a complex design setting, for this work, it is established that typical riverfront design typologies will be identified and that HSW standards for accessibility will be a foundation for application of generative modeling to a “test site” on an urban riverfront site. The effectiveness of generative modeling’s application to urban riverfront landscape design typologies, such as path network systems: (linear geometries of path, edge, wall, and intersection) is evaluated and discussed. All of these characteristics are fundamental aspects of urban riverfront design work.

In this study, the process of generative modeling design consists of developing algorithms based parameters derived from recognized urban riverfront designs and HSW standards to create prototype geometric form profiles for riverfront path systems. Exploring and understanding the relationships between the horizontal and vertical planes and the forms and systems they create is one of the ambitions for this study. The use of parameters and generative algorithms as an effective technique for form exploration is intended to develop a clearer understanding of whether the methods of parametric and generative modeling can be useful in the practice of landscape architecture.
The key objectives are: (1) demonstrate that parametric and generative design processes can be applied to landscape systems, (2) develop an understanding of how site typologies affect the HSW algorithms used in the design, (3) analyze and evaluate the application of using generative modeling to a landscape typology, and (4) document how use of these tools and procedures contribute to the design experience and understanding.

1.1 Justification

Generative modeling using parameters is a process that has been used frequently in structure and facade design, but has been used very little in landscape architecture. This suggests that exploration of this type of process in the field of landscape architecture is needed. Often, the process of design undergoes numerous changes and causes the design to be done in phases. This can cause the design to lose holistic unity and the criteria can be ignored or not responded to, or in a worst case scenario, lost in the process. In some cases, the relationships between these changes and alterations may be difficult to understand and document, and adjustments are made without recognition of prior parameters, such as which HSW standards applied or what the design program dictated. In the attempt to improve the understanding and documentation of origins of design geometries and relationships, technology has evolved to help reveal, document, and recognize design procedures and paradigms more effectively. Generative modeling using parameters provides rapid exploration of multiple iterations in an interactive design process, allowing potentially the “best” scenario evaluation and theoretically should result in improved outcomes. Examining and applying generative modeling to a
landscape architecture typology, such as an urban riverfront system, may have potential to support designers in maintaining adherence to critical HSW standards and requirements for public spaces.
CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

At first glance, much of the literature discussing the theory and practice of parametric and generative modeling is directed towards structural and architectural form-finding. After reviewing and becoming familiar with the vernacular and theories behind parametric modeling, the concepts and applications can be applied to many design typologies. It is said that the idea of parametric design developed from the first computer-aided design system called Sketchpad developed by Ivan Sutherland. Sutherland’s 1963 PhD thesis at MIT is credited to be the first documented mechanism that used a constraint language in computational design. Many authors discussing these notions of this type of digital modeling consistently use the same language and approach the idea of form-finding using parameters as a systematical and logical process with an emphasis on mathematics and generative algorithms. Fulvio Wirz defines Parametric modeling as design, “...not generated by a layered mechanism or parties’ assembly, but rather through definition laws, which control its generation and differentiation. The result is a complex order where every element is continuously connected and the project achieves a self-referential condition where you can make changes, preserving the whole concept” (Fulvio Wirz, 2011).
Much of the discourse breaks parametric modeling into two types of design (Milena and Ognen, 2010). Type one is *conceptual parametric design* and type two is called *constructive parametric design*. In conceptual design, the parameters of a particular design are declared, not its exact produced shape. In constructive design, data is embedded with a predetermined 3d object, such as windows and doors or other repetitive pre-drawn elements. Based upon these types of parametric design methods, this study will focus on the conceptual parametric modeling, otherwise known as form-finding. Based on the definition of form, form-finding is an exploration of shapes and thus will have a degree of values and variables to be applied to the process of design. The form of riverfront path networks will be explored using the concepts, design standards, and fundamental theories used in riverfront design with the added input of parameters developed by analyzing recognized riverfront designs. The theories of parametric and generative modeling identified in the literature reviewed will be applied to this study.

### 2.1 Historical Overview

“Generative Modeling” describes a paradigm change in shape direction, the generalization from objects to operations: which the shape is described by a sequence of steps, rather than the end result of applying operations,” (TU Graz, 2012). The generative modeling process can be understood as a cyclical process that is based on algorithms and the designer of that algorithm. Inputs and variables can be applied to the algorithm which consequently changes the output of that modeling process (figure 1).
Figure 1: Generative Modeling Concept Diagram illustrating concepts of algorithms and generative modeling based on algorithms and an iterative process, which is cyclical in nature. By using this process models can be generated, evaluated, and changed based on new inputs or parameters that are applied to the design. (Meier, 2012)

Since the 1950’s, there has been a design process paradigm shift. “…the mechanistic understanding of nature and the continuous top-down reduction of the whole into parts has been exchanged from patterns of local interaction to the overall global arrangement of the parts as an emergent bottom-up property of the overall system (Kutnik, 2010).” In 1963, the development of “Sketchpad” by Ivan Sutherland was the first major computer oriented parametric system (Woodbury, 2010). The development of this type of tool and process used graph-based approaches and allowed for designs to really examine and use geometry as the basis of digital design methods (figure 2).
Figure 2: An illustration of the history and evolution of digital design and parametricism. By 1963, Ivan Sutherland’s development of “Sketchpad” created opportunities for new methods of design and geometry applications in design processes. (Meier, 2012)

The primary framework for this study was established through the ideas mentioned in the Digital Cities reading (Leach, N. (2009). The notion of parametricism is based on five goals that are intended to enhance the quality of design. These five goals are the following: (1) interarticulation of subsystems, which is the differentiation in any system, is correlated with differentiation in other systems, (2) accentuation, which is the articulation is achieved through visual information that is made available, (3) figuration, which is changing quantitative values results in qualitative shifts in perceived configurations, (4) responsiveness, which is the built environment acquires responsive patterns at timescales, and (5) deep relationality, which are the systems that possess strong integration and evolving outputs when inputs are added. A major part of the
projects framework was based on the research done by Frei Otto. Frei Otto’s work on path networks and the development processes of urbanization can help establish a framework on the “distinctions and relations of occupying and connecting” urban spaces. He bases his analysis on the notion of connection and how these patterns are influenced by *distancing* and *attractive occupations*. Fundamentally, every path network has a point of beginning and end (*attractive occupations*), and between those occupations are some organizational geometry (distancing) that connects those points. Due to the associative or inter-relationship nature of these two concepts, “relational fields” begin to emerge and illustrate patterns of connection. The organization and evolution of these geometries can articulate a visual illustration on how cities form from these emerging path networks. Simply put, path creates space, while space creates path. Otto differentiates the process of connection into three types of path networks, which each have a sub-set of configurations. The three levels of path networks are settlement networks, territory networks, and long distance networks. Each of these networks can be configured into direct path networks, minimal path networks, and minimizing detour networks. For each set of path configurations optimal solutions can be produced based on the desires or needs of that parametric space.

Otto’s research was based on two fundamental notions of two fundamental activities of Occupying and Connecting in urbanization processes. Otto postulated that though there may not be one unique optimal solution, and each computation is different, characteristic patterns emerge in different regions of parametric space (figure 3).
2.2 Literature Review

The literature review for this study can be divided into three topical areas. First, an understanding of computational design must be acquired. Second, the basic mathematics and geometry used in generative modeling must be explored. Thirdly, research of algorithms and how they apply in design and the digital realm is needed.

2.2.1 Computational Design

The innovative and constantly evolving realm of technology has brought the emergence of numerous methods and tools available for architecture and design. With these emergences there has been controversy on the impact that technology has on processes and production in design. Terzidis (2006) states “For many designers, the computer is just an advanced tool running programs that enable them to produce sophisticated forms and to control better their realization”. He continues with explaining that the computer should not be viewed as an addition of the mind, but rather as a partner in the process with different methods of logic and capacities.
Since generative modeling is under the umbrella of digital design, there are some key concepts and information that must be identified and explicated. The digital world of design is carried out through quantifiable data, which usually conceptualized or measured by the designer. The basic idea behind computational design is called computerization, which is “the act of plugging in data, manipulation of the data, and then storing the data (Terzidis (2006).” Benjamin Fry explains in his dissertation from 2004 on how to understand and work with data in computational design (figure 4).

Figure 4: The image shows Benjamin Fry’s research working with data in computational design. Source: Fry, B. J. (2004). Computational Information Design. Massachusetts: Massachusetts Institute of Technology

In order to understand data in computational design the designer must (1) acquire the data, (2) parse, or order the data, (3) filter, which is to remove unnecessary data (4) mine, which is to apply data in mathematical context, (5) represent the data visually, (6) refine or clarify the data, and (7) interact with the data (Fry, 2004).
2.2.2 Mathematics and Geometry

In generative modeling (all visual computational design) there are mathematics and geometry which underlie the output, and those mathematics must be understood in order to carry out certain operations and to generate design. The three basic elements of mathematics in digital modeling are vectors, matrix operations, and parametric curves and surfaces with focuses on “NURBS”, or Non-Uniform Rational B-Splines, as named by Robert McNeel and Associates (2012).

Vectors are represented with lines and points that have a quantity of direction and/or force (figure 5). Vectors can be understood as a quantity that has “direction” and “magnitude”. They have a value or direction, and anchoring those values or directions are points. Points and vectors can be represented in a 2-D coordinate system, or a 3-D coordinate system. Correspondingly, in 2-D coordinate systems vectors are represented by two real numbers, while in 3-D systems vectors are represented by three real numbers. All objects in space must have a spatial point of beginning, otherwise known as the origin point. This special vector from the origin point is called the “position vector”, and is the only vector represented as \( P_0 = (0, 0, 0) \), and \( P_1 = (a_1, a_2, a_3) \).

Once the position vector has been represented, vector operations can now be performed. All vectors have properties and can operate functions of addition, distancing, scaling, and multiplication. These definitions and functions are evaluated by proofs, laws, and theorems that can be evaluated by generative modeling software tools such as Grasshopper\textsuperscript{TM}. The vector equation of a line can be achieved by defining the line, direction vector, and point components in space. The vector equation of a plane, or
surface, can be defined by a series of lines, direction vectors, and point components (figure 5). Vectors are the foundation for object construction in digital space, and must be understood before going any further in generative modeling.


When any object in space moves, rotates, projects, or rescales, there are mathematics that occur on that object (figures 6 and 7). This system of mathematics is called transformation matrices. Transformation can be defined as, “a function that takes a point or vector and maps that point into another point,” (Issa, 2010). A matrix is what defines those transformations, and allows those relationships to be understood in the coordinate system. A matrix is defined as a rectangular array of numbers, that are aligned into rows and columns that have a dimension. The crucial element of matrices is that they are translatable and allow the computational design to be transformational. Similar to vectors, matrices can also experience transformation operations such as multiplication, affine, rotation, scale, shear, and projection changes. In generative modeling there can be multiple matrix operations performed on an object at one time.
Figures 6 and 7: These images illustrate how matrix transformations occur on an object and how the data for the object can be tracked and evaluated based on coordinates in model space. Source: Issa, R. (2009). Essential Mathematics for computational design. Seattle, Washington: Robert McNeel and Associates.
Curves and surfaces are often highly compact geometries that have a high number of points and lines that have a direct relationship on the smoothness of the geometry or shape. The more dramatic the curve, the higher the number of points and lines are needed in order to keep that curve, and consequently that curve or shape is harder to manage. Curves can take many forms and geometries, but which all share similar properties of continuity and curvature. Cubic polynomial curves, such as Hermite and Bezier curves are two of the basic curves (figure 8), while NURBS curves and surfaces have a wide range and can generate much more complex geometries. The concept behind parametric curves allows editing and maintaining the curves ability to store the points and vectors that generate that geometry. Parametric representation of a curve can be expressed as functions of variable $t$ (figures 9 and 10). The variable $t$ stands for any parameter, or value along an interval $(I)$ of a curve (Pottmann, Asperl, Hofer, and Kilian, 2007). The parameter or variable can be managed, altered, and evaluated. Parametric curves and surfaces focus on the notion of NURBS and continuity (figure 11). NURBS stand for “Non-Uniform Rational B-Splines, which are mathematical representations of 3-D geometry that can accurately describe any shape from a simple 2-D line, circle, arc, or curve to the most complex 3-D organic free form surface or solid (Robert McNeel and Associates, 2012). In generative modeling, these complex geometries and forms can be created and evaluated in a systematic and linked manner, thus allowing for a visual understanding of how these geometries and properties are produced.
Figure 8: A Hermite curve has two end points, which control the shape of the vector. A Bezier curve has four points, which the two points outside the curve (P1 and P2) control the geometry. Source: Issa, R. (2009). Essential Mathematics for computational design. Seattle, Washington: Robert McNeel and Associates.

Figures 9 and 10: A parametric curve that is determined based on a parameter (variable t) over some beginning and end domain. The parameter (variable t) can be changed and evaluated through a function, and altered along the curve. Source: Issa, R. (2009). Essential Mathematics for computational design. Seattle, Washington: Robert McNeel and Associates.
2.2.3 Generative Algorithms and Parametric Architecture

In every procedure there is a beginning, an end, and everything that occurs between. Generally speaking, this procedure from start to finish is called an algorithm. “An algorithm is a procedure for addressing a problem in a finite number of steps using logical operations” (Terzidis 2006). Though algorithms are often used in mathematics, the concept of algorithms can be understood and applied to everyday events and activities. For example, if you are driving and want to switch lanes there is a logic and order in which to achieve that act (figure 12). The same concept can be applied to design.

Figure 12: The algorithmic process of switching lanes while driving. Source: The Turner-Fairbank Highway Research Center (TFHRC) Office of Research, Development, and Technology, Office of Operations, RDT
You have a problem or desired outcome, and need to think how to produce that output. In design fields, generative algorithms are used in order to carry out the operations of exploration and discovery of potential models aiming to produce the optimal design scenarios based on the input data of the algorithms. “Generative modeling uses a method where elements are connected in a fixed order, which produces a result crating a basis for building a new order, (Milena and Ognen, 2010)”. Essentially, generative modeling uses numbers and parameters to negotiate the design, and possesses a logical and geometrical inter-connectivity that is visible.

Terzidis provides a perhaps biased, but yet compelling argument on how using the computer and digital design using algorithms doesn’t hinder the human’s role in design, but rather increases the possibilities and enhances the creativity of design. He states that “we shouldn’t consider the computer as an extension of the mind, but rather a partner in the design process with different aptitudes and ways to reason. The computer is the “other” human mind” (Terzidis 2006). Throughout the book, the author explains in depth of what algorithms are, how they work, and how they can be applied to design as a mathematical approach.

Stavric Milena and Marino Ognen (2010) offer a good overview on the basic concepts of parametric design and how generative algorithms can be applied to architectural design. Digital modeling has become a typical tool used in design, and has been a large part of the technological advancements in software applications. These advancements have been the platform for further computer aided methods in design,
consequently resulting in generative modeling developments. The desire for architects, landscape architects, and planners to be able to “generate and explore a broad range of designs that can be changed interactively” (Stavric and Marina 2011), has brought generative modeling processes within the dialogue of design. The article offers clear definitions of generative algorithms and the dialect associated with generative modeling. Often referred to as associative modeling or parametric urbanism, generative modeling is suggested to replace the old concepts of design. The authors state that “existing concepts in theory of architecture and urban form design are based on fixed typologies and do not provide solid ground for understanding the process of creation of form and the phenomenon of urbanity in general” (Stavric and Ognen 2011).

Milena and Ognen (2010) establish and discuss a framework on the recent paradigms in architecture and how they have helped contribute to the evolution of parametric modeling as part of the design process. The authors explain five key reasons on why this design theory has emerged and how algorithms evolved out of these design paradigms. First, individualization is where every property of a distinguishing element is a consequence of accumulation and interaction of different impacts, circumstances, and limits. Second, topological paradigm is where uniqueness and locations of the elements within the system are determined entirely through its relation with all other elements of the system. Next, population of elements is the notion of having a decentralized or dispersed order of the parts of the design. Fourth, the idea of multiplicity or variety of parts is when the components and neighboring relationships create the order of the system and are the source of a “morphogenesis” process. Lastly, understanding the
productive differences that increase the process of adaptation and changes that occur in the system can be used in the design process. Each change in geometries can have a direct effect on the next geometry or generated form.

Figure 13: The diagram illustrates the idea of how each change and rotation of the square occurs, geometries and form emerges with relation to the previous shape. Source: Generative Scripting II; Collections and Resources of Student Work; (2012)

Figure 14: This image illustrates how algorithms can be used to generate a design and captures the idea of “morphogenesis”. Source/Publication: Proceedings of the 26th eCAADe Education and Research in Computer Aided Architectural Design in Europe 2008, Authors: Sean Hanna, A Kanellos
The authors then briefly discuss how the concepts of parametric modeling have reached the urban scale and the dynamics that cities possess. Parametric urbanism is a concept used to understand the dynamics between socio-cultural and material processes that shape cities today. The generative modeling process is based on the organization of the networks and the interrelated systems. These models can produce an “emergent order” in which are derived from the diverse agents and conditions of the systems in place. They conclude in reiterating the role that digital modeling such as parametric modeling and generative algorithms have on studying and understanding the form and systems in architecture of today’s complex environments.

Shajay Bhooshan and Mostafa El Sayad (2010) were helpful in providing a strong sense of how to approach and set up the framework and structure for evaluating parameters in form-finding studies. The core of the article focuses on the technical aspects of sub-division in building design, but the ideas and methodologies used can be applied to many types of parametric modeling procedures and projects. For instance, the research suggest that in site design there are iterative studies that are vital in the evolution of the design itself, and working with simulation tools and parametric applications can improve the speed and intuition of the designers workflow. The research emerged out of the argument in support for “parametric design research to focus on design methods that enable an operative pathway from design intent to its manifestation”, (Bhooshan and Sayed 2010). The authors examine how physically-based parameters are effective constraints in conceptual design, and can create a strong interaction between the designer and the computer.
CHAPTER 3

URBAN RIVERFRONT CASE STUDIES

In order to apply the generative modeling tool to a site, there must first be a landscape architecture project or design setting selected. The selected landscape architecture setting for this study was urban riverfronts. This setting is selected because in urban riverfront projects there are often similar themes that occur, as well as similar constraints and spatial limitations (i.e. water’s edge and safety standards). The forms that make up urban riverfronts are often linear or curvi-linear, and possess a repetitive geometry that keeps the design unified and consistent. For example, many of the riverfront vision plans reviewed all shared common goals and objectives for the designs. Most plans stated that the urban riverfront must provide easy access and entry/exit, have a balance of uses, and preserve natural or wooded riparian areas. Based on the Columbus Riverfront Vision Plan (1995), “The river corridor will host recreational activities and informal leisure use that will make it safe and a resource for running, bicycling, skating, and walking will be possible on continuous trails integrated into the environment with winding pathways, occasional river overlooks, pedestrian bridges, and observation areas”. These inherent design guidelines and concepts are considered when evaluating and analyzing the case studies.
The purpose of the case study analysis is to identify typologies that make up the urban riverfront systems, the function, form and relationship of these typologies, and quantifiable data that can be derived and applied to the generative modeling process to be used on the test site. The case studies provide the information and data for the application of generative modeling.

After all the case studies are analyzed, four consistent site typologies were identified. There are access typologies, “belvedere” typologies, switchback typologies, and “promenade” typologies (case study diagrams in sections 3.1 – 3.3). The access typology can be defined as the areas and paths that connect the site to the surrounding context and places within the site. The “belvedere” typology is defined as areas of view or vantage points. The switchback typology is identified as areas and paths required to accommodate for steep grade and directional changes. The “promenade” typology is defined as paths or areas along the river’s edge. For each case study, each site typology was examined, located, and measured through cross sections and photographs to understand each typological condition, as well as the dimensional range and parameters associated with it.
3.1 Case Study 1 – Louisville Waterfront, Louisville Kentucky

Image 1: Louisville, Kentucky Waterfront aerial, 2012, Google
3.1.1 Louisville Waterfront Access Typology

Figure 15: Louisville Waterfront Access Typologies (black paths) (Meier, 2012)

Images 2 and image 3 (Photos by Derek Cashman); Louisville Waterfront Access typology conditions

Figure 16: Analysis: cross sections of Louisville Waterfront Access Typologies (Meier, 2012)
3.1.2 Louisville Waterfront Belvedere Typology

Figure 17: Louisville Waterfront Belvedere Typologies (black paths) (Meier, 2012)

Images 4 and 5: Louisville Waterfront Belvedere typology conditions

Figure 18: Analysis: cross sections of Louisville Waterfront Belvedere Typologies (Meier, 2012)
3.1.3 Louisville Waterfront Switchback Typology

Figure 19: Louisville Waterfront Switchback Typologies (black paths) (Meier, 2012)

Image 6: Switchback typology conditions; source URL: http://skyshotsblimpcam.com/

Figure 20: Analysis: cross sections of Louisville Switchback Typologies (Meier, 2012)
3.1.4 Louisville Waterfront Promenade Typology

Figure 21: Louisville Waterfront Promenade Typologies (black paths) (Meier, 2012)

Image 8: Louisville Waterfront Promenade typology conditions; Source URL: http://landscapeonline.com/research/article/7366

Figure 22: Analysis: cross sections of Louisville Waterfront Promenade Typologies (Meier, 2012)
3.2 Case Study 2 – Olympic Sculpture Park; Seattle, Washington

Image 9: Olympic Sculpture Park; Seattle, Washington aerial, 2012, Google earth
3.2.1 Olympic Sculpture Park Access Typology

Figure 23: Olympic Sculpture Park Waterfront Access Typologies (black paths) (Meier, 2012)

Images 8 and 9: Olympic Sculpture Park Access typology conditions (2012, Google earth)

Figure 24: Analysis: Cross sections of Olympic Sculpture Park Access Typologies (Meier, 2012)
3.2.2 Olympic Sculpture Park Belvedere Typology

Figure 25: Olympic Sculpture Park Belvedere Typologies (black paths) (Meier, 2012)

Images 10 and 11: Olympic Sculpture Park Belvedere typology conditions (2012, Boxtop design architecture design news and pictures)

Figure 26: Analysis: cross sections of Olympic Sculpture Park Belvedere Typologies (Meier, 2012)
3.2.3 Olympic Sculpture Park Switchback Typology

Figure 27: Olympic Sculpture Park Access Typologies (black paths) (Meier, 2012)


Figure 28: Analysis: cross sections of Olympic Sculpture Park Switchback Typologies (Meier, 2012)
3.2.2 Olympic Sculpture Park Promenade Typology

Figure 29: Olympic Sculpture Park Promenade Typologies (black paths) (Meier, 2012)

Image 14: Olympic Sculpture Park Promenade typology conditions (2012, Google earth)

Figure 30: Analysis: cross sections of Olympic Sculpture Park Promenade Typologies (Meier, 2012)
3.3 Case Study 2 – North Bank Park; Columbus, Ohio

Image 15: North Bank Park aerial (2012, Google earth)
3.3.1 North Bank Park Access Typology

Figure 31: North Bank Park Access Typologies (black paths) (Meier, 2012)

Image 16: North Bank Park Access typology conditions (2012, Meier)

Figure 32: Analysis: cross sections of North Bank Park Access Typologies (Meier, 2012)
3.3.2 North Bank Park Belvedere Typology

Figure 33: North Bank Park Belvedere Typologies (black paths) (Meier, 2012)

Image 17: North Bank Park Belvedere typology conditions (2012, Meier)

Figure 34: Analysis: cross sections of North Bank Park Belvedere Typologies (Meier, 2012)
3.3.1 North Bank Park Access Typology

Figure 35: North Bank Park Promenade Typologies (black paths) (Meier, 2012)

Image 18: North Bank Park Switchback typology conditions (2012, Meier)

Figure 36: Analysis: Cross sections of North Bank Park Switchback Typologies (Meier, 2012)
3.3.1 North Bank Park Promenade Typology

Figure 37: North Bank Park Promenade Typologies (black paths) (Meier, 2012)

Image 19: North Bank Park Promenade typology conditions (2012, Meier)

Figure 38: Analysis: Cross sections of North Bank Park Promenade Typologies (Meier, 2012)
3.4 Case Studies Summary

After all the case studies were performed, there was an extraction of quantifiable data from the cross sections. These numbers were organized, evaluated, and filtered. The path widths were documented, followed by established ranges of each typology for each case study, and eventually all the case studies typology ranges were combined (table 1). These numbers and geometric data were used later in the algorithm development and iteration process that will be explained later in this paper.

<table>
<thead>
<tr>
<th>Case Studies Dimensions Extracted from Section Study</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typology Widths (ft)</strong></td>
</tr>
<tr>
<td><em>Louisville Waterfront Park; Louisville, Kentucky</em></td>
</tr>
<tr>
<td>Access Typologies</td>
</tr>
<tr>
<td>Belvedere Typology</td>
</tr>
<tr>
<td>Switchback Typologies</td>
</tr>
<tr>
<td>Promenade Typology</td>
</tr>
<tr>
<td><em>Olympic Sculpture Park; Seattle, Washington</em></td>
</tr>
<tr>
<td>Access Typologies</td>
</tr>
<tr>
<td>Belvedere Typology</td>
</tr>
<tr>
<td>Switchback Typologies</td>
</tr>
<tr>
<td>Promenade Typology</td>
</tr>
<tr>
<td><em>Northbank Park; Columbus, Ohio</em></td>
</tr>
<tr>
<td>Access Typologies</td>
</tr>
<tr>
<td>Belvedere Typology</td>
</tr>
<tr>
<td>Switchback Typologies</td>
</tr>
<tr>
<td>Promenade Typology</td>
</tr>
</tbody>
</table>

Table 1: This table shows all the data extracted from the case studies. In this study, path widths were numerical data that was later used in the application process. (Meier, 2012)

3.5 Health, Safety, and Welfare Standards

In all fields of design in the physical and built environments, there are criteria and rules that need to be followed. The health, safety, and welfare standards applicable to urban riverfront design were also researched and identified (table 2). These HSW
standards were documented and used in the application process when generating the algorithms for the site design. The evaluation process was also done by using these standards that served as criteria for dismissing any iteration of the typologies using the generative modeling tools and methods.

<table>
<thead>
<tr>
<th>Timesaver Standard Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Access Route Criteria</strong></td>
</tr>
<tr>
<td>Max height btwn ldings shld be 5 ft.</td>
</tr>
<tr>
<td>Urban area path width min. 48 in.</td>
</tr>
<tr>
<td>Natural area access path width 36 in.</td>
</tr>
<tr>
<td>Maximum grade of 8%</td>
</tr>
<tr>
<td>Maximum cross slope of 3%</td>
</tr>
<tr>
<td><strong>Pedestrian Criteria</strong></td>
</tr>
<tr>
<td>Minimum path width of 4 ft.</td>
</tr>
<tr>
<td>Minimum distance of 30 in. from street edge</td>
</tr>
<tr>
<td>Maximum distance of 700 ft. of path</td>
</tr>
<tr>
<td>maximum slope of 5%</td>
</tr>
<tr>
<td>Maximum landing distance of 30 ft.</td>
</tr>
<tr>
<td>Minimum cross slope of 1%</td>
</tr>
<tr>
<td>Maximum cross slope of 3%</td>
</tr>
<tr>
<td><strong>Bicycle Criteria</strong></td>
</tr>
<tr>
<td>Minimum path width of 8 ft.</td>
</tr>
<tr>
<td>Preferably 5% maximum slope</td>
</tr>
<tr>
<td>Curve Radii range 95-565 ft</td>
</tr>
<tr>
<td>Maximum cross slope 1%</td>
</tr>
</tbody>
</table>

Table 2: The table identifies all the Health, Safety, and Welfare standards extracted from Time Saver Standards (1998) and the Access Standards established by the federal government (2010).
CHAPTER 4

APPLICATION OF GENERATIVE MODELING TO SITE

The potential test sites that were considered for the application of generative modeling on a landscape typology looked at urban riverfronts along the Olentangy Riverfront in Columbus Ohio. The search for the test site selection aimed to locate a dynamic riverfront that was situated in an urban setting with many contextual connections. Some of the test sites that were considered were sites along the Lower Scioto Greenway or the Olentangy Trail. After consideration, the riverfront southeast the Confluence Park was selected. The reason for selecting this site was that the riverfront appeared slightly under developed and disconnected from the rest of the surrounding riverfronts of the city. The test site is located east of 315 interstate and north of the Franklinton neighborhood in Columbus, Ohio. The site is also directly across North Bank Park, one of the case studies that were examined earlier. This site is located along a riverfront that has a dynamic relationship with the downtown area of Columbus, Ohio. These site elements and qualities sparked an interest in how the generative modeling tool could be applied and implemented in the design process of this urban riverfront typology.
The site selected to have the generative modeling process applied is located east of 315 interstate and north of Franklinton Columbus, Ohio. Also, directly south across from North Bank Park.

Once the test site was selected a field analysis was performed. Earlier research found in the literature review was applied to the field analysis. The concept of “Attractive Occupation and Distancing” from Frei Otto’s research was used to set up the field analysis (figure 39). Otto’s research provided an interesting and compelling concept on how to evaluate urban space, and this notion would help conceptualize how real spatial elements and conditions could be translated and understood in a parametric modeling tool and system, such as generative modeling.
During the field and site analysis, nodes of attraction, nodes of intersection, detractors and limitations, views, and connection were all themes that were incorporated into the site analysis process. Also, key access points were considered and documented during this process as well. These key access points were where the existing bridges connected to the site and along the southern edge where the Franklinton neighborhood streets connected to the site. The constraints, or detractor areas of the site consisted of the railroad system, SR 315 highway, and wooded areas in order to preserve wildlife areas (figure 40). Another key part of the site analysis is slope and view documentation. There
was a direct relationship on topography and views that were provided on the site. The four places identified on the site for views were high points, ridge lines, edge lines, and crossing vantage points (figure 41. The key access points and attraction points were than extracted from the field analysis and documented in another diagram (figure 42). After the field analysis site diagrams were completed, the application of generative modeling to the site was ready to begin.

Figure 40: Constraint and limitation areas identified as “detractors”
Figure 41: Slope analysis and the relation of views that the site provides to the surrounding context are documented. These features and concepts were applied to the next stage of building the algorithm and applying the generative modeling process to the site.

Figure 42: Diagram of potential access points and identified attractor areas in the site.
4.1 The Algorithm

There are many generative modeling software programs available for designers to use and explore. Some of these programs are Bentley Generative Components, Bootcamp, K3DSurf, VMware, Paracloud, and Grasshopper™ just to name a few common generative modeling programs. Due to familiarity and access to the software platform Rhino 4.0, the plug-in Grasshopper™ 3-d was chosen as the generative modeling tool that would be used in the application process to the urban riverfront site along the Olentangy.

Grasshopper™ 3-D is a generative modeling tool that uses visual algorithms to generate models, designs, and different geometries. The plug-in Grasshopper™ has geometries, operations, and functions that are used in order to visually see how the system is interconnected, and how manipulation of these geometries have interdependent qualities (figure 43).

Figure 43: The visual algorithm editor in the Grasshopper™ interface and its different components that are used in the workspace. Parameters, components, geometries, and evaluation tools are all part of what Grasshopper™ has in its tool pallet.
The designer uses these tools to produce numerous models and scenarios that can be evaluated and documented based on design requirements (Tedeschi, 2010). The algorithm is created in the Grasshopper™ interface, and then shows the preview geometries in the rhino model window space (figure 44).

![Grasshopper Preview Geometries](image)

Figure 44: Some preview geometries of points, lines, and surfaces generated through the Grasshopper™ plug-in

The development of the generative algorithm for the site began with taking the access points from the field and site analysis and buildings those points into the parametric model space coordinate system (figure 45). Since the access points are
connected to the streets, they are fixed points in the parametric model space. The next part of the application process added the attraction area points. These points were given x, y, and z coordinate placement. These points were not fixed and could be adjusted by the number sliders, which control the dimensions (parameters) of the generated models, (figure 46). After the access points and attractor points are identified in the workspace, there were logical direct connections generated and identified by the designer (figure 47).

Figure 45: Access points in rhino workspace
Figure 46: Attraction Points created in Grasshopper™ that generated in the rhino model space

Figure 47: Logical Direct connections chosen by the designer
After the direct connections were identified and created, the connections were categorized based on the typologies that were established in the case studies. The direct connections were organized into access typology connections, belvedere typology connections, switchback typology connections, and promenade typology connections were illustrated (figures 48-51). This organization process was able to provide the designer with an abstract idea of where these typologies could be on the site, and how some patterns related to each typology began to emerge through the generative process. These typologies were examined and evaluated in more detail later in the application process, which ultimately resulted in the designer choosing the best or preferred design for the site.

Figure 48: Direct access paths between access points and attractor points
Figure 49: Direct belvedere paths between attractor points

Figure 50: Direct switchback connections between access and attractor points
Once the direct connections were examined and evaluated, the generative algorithm for the site began to develop and take a more complex form. Beginning with the access typology, the path system was developed based on identifying the elevation change from each point. For example, the difference in elevation (in z-coordinate system in model space) from the access points to the elevated pedestrian bridge over the railroad tracks was determined. Those changes in elevations allowed the designer to use the HSW criteria to establish a number of standards to be incorporated into the site algorithm. They major HSW standard that was used in developing the generative model was the amount of landings that must exists in the path system in order to meet safety and access criteria. Based on the HSW criteria, the maximum elevation change between landings can be 5 feet, or 5% slope. After elevation differences were determined between the points in the model space, the designer was able to know the amount of landings there must be in
order to meet the HSW standards. After all points and lines were created, surfaces were added. The site algorithm was built and became to be understood as parts that made up the whole site system (figures 52, 53, and 54).

Figure 52: The generative algorithm for the entire site. Each color represents a different typology on the site. Red is access typology, yellow is switchback typology, blue is promenade, and purple is belvedere typology.

Figure 53: The illustration shows a close up of how the landings are set up in the generative modeling workspace of Grasshopper™. The yellow boxes are evaluative pieces showing the distances between each landing. In order to meet the HSW criteria, each path must remain greater than or equal to 100 feet.
Figure 54: The entire path system that is created through algorithms in Grasshopper™. This path system is not fixed or the recommended design, with the exception of the fixed access points that connect to the south end of the site.

4.1 The Iterative Process

Now that the algorithm was created, the iterative process can begin. As part of the process for all design practices, design development consists of looking at varying models and schemes that are possible. Sketching by hand or using the computer are both ways in exploring these potential models and schemes. By exploring different models and scenarios designers are able to create and discovery potential outcomes for the design. In parametric modeling, design standards are predetermined, and applied to the exploration process. This allows for the “sketching” or iteration process to have the criteria of HSW standards built into the exploration process, and could result in reducing the cross checking of design possibilities and if they meet standards that are relevant to each design. In this study, the iterations criteria were primarily based on the maximum slope of
5%, the maximum distance of path between landings of 700 feet, and minimum path width of 8 feet.

As mentioned previously, the landings were the controlling devises used for the duration of the iterations. Each landing had a fixed z-axis applied to it, while the x and y axis were able to be freely altered based on the designers discretion. In the access typology iterations, there were 6 landings required to meet HSW standards when creating a path between the access point and the intersection point of the elevated pedestrian path (figure 55).

Figure 55: Access path iteration base with landings. Landings are fixed elevations, but can be altered across horizontal space.
Figure 56: Access path iterations with HSW criteria applied to eliminate iterations that do not meet HSW standards.
The iteration process continued through all the typologies that were identified for this study (Figures 57-62). Each iterative process used the same HSW criteria to evaluate the iterations, and eliminate the iterations that did not meet standards. From the iterations that met the HSW standards, the designer selects preferred or optimal design scenarios.

Figure 57: Belvedere Iterations with HSW criteria applied to eliminate iterations that do not meet HSW standards.
Figure 58: Belvedere Iterations with surface geometry added
Figure 59: Selected/Preferred Belvedere Iterations

Figure 60: Selected/Preferred Promenade Iterations
CHAPTER 5

CONCLUSIONS AND EVALUATIONS

The evaluation of the generative modeling application to the design experience can help answer the three initial research questions. (1) What can generative modeling offer to the theory and practice of landscape architecture? (2) Where can generative modeling be applied in landscape architecture? (3) What is the design experience inherent in the process?

Generative modeling tools and methods may offer some interesting potentials and opportunities to the field of landscape architecture. In landscape architecture there are often elements and features that are repetitive and always must adhere to certain parameters (steps, ramps, handrails, etc.). The generative modeling process used the case studies to develop landscape typologies that may normally be uncategorized or un-established as a typology in the urban riverfront system. Generative modeling can offer the ability to explore these common design elements with some variation, while discovering design possibilities that meet criteria that are established in advance, thus saving time later in the design phases. Additionally, because the algorithms are created in a “bottom-up fashion”, they are able to be connected and used in other phases of designing a larger system, such as connecting one riverfront area to another.
Designs and projects evolve out of an experiential quality and process, so an evaluation of generative modeling in the design experience must be expounded. The research of generative modeling suggests that there are many applications that are available in the field, and perhaps the best generative modeling tool is a case by case base, as well as a designer to designer base. Based on the generative modeling tool and process applied and used in this study, there are a number of pros and cons which must be identified and evaluated. The application of this method to the design process helped create the ability to run and produce multiple iterations very rapidly, while also evaluating those iterations rapidly according to the health, safety, and welfare standards that were established prior to the iterative process. Also, the immediate visual understanding of how the parts of the design are connected, changes, and make up a larger system helped in the conceptualization of the urban riverfront system in place. The cons, or negatives of this method in the design experience is that initial set up of these algorithms can be a lengthy process, depending on how complex the system that your designing or modeling. Though the learning curve can be high, using the generative modeling tools and software may require high levels of organization during the algorithm development stages. A key part of the evaluative process was that in Grasshopper™ only one variable can be manipulated at a time. Though manipulating one variable can change multiple parts of the design, only one variable can be evaluated and understood in the iterative process.

In professional practice, parametric tools and applications have been used and is becoming to be seen as a potential tool applied to landscape architecture design processes. Based on presentations given by Gary Stewart, an employee of Woolpert
Incorporated, as well Tony Murry from NBBJ, an international design firm, their companies are using parametric tools as a way to examine and select optimal and cost effective designs. By applying generative modeling techniques they are able to explore design options in a systematic way to reach optimization in certain aspects of the design.

Future research pertaining to the field of generative modeling is extensive in possibilities. Currently, the realm of digital design tools and technology is constantly evolving, so the potential and desire to explore new technologies and tools available to use in the design processes is quite popular and needed. Through much of the literature review on parametric design, using generative modeling software to explore and evaluative patterns at the large urban scale is gaining support and use in research. Perhaps, applying the generative modeling tool to “parametric urbanization” studies may be a future study. Also, applying generative modeling to a different landscape architecture typology or element other than paths could be of future interest.

This study has provided some understanding and opened doors in exploring the large and evolving field of generative modeling. The digital world in design is constantly changing and in order to keep up with these tools and methods designers must continuously research and use new and innovative techniques, while still keeping in mind and considering the same underlying principles and purpose of design in the built environment. A goal of design in the built environments is to improve the quality of life for humans and the environment. Use of tools such as generative modeling is a means to enhance quality design.
Bibliography


APPENDIX

ADDITIONAL ITERATIONS REVIEWED

The iterative process performed during this study consisted of using generative algorithms to generate numerous models for the four typologies identified in the case studies. In the body of the document the illustrations and figures for the access and belvedere iterations were illustrated, but the promenade iterations were not illustrated. This appendix shows the iterations ran for the promenade typologies during the investigation of applying generative modeling to the urban riverfront test site.
Figure 61: Promenade Typology Iterations
Figure 62: Promenade Typology Iterations (Perspective View)