The Parametric Process: A Strategic Analysis on Digital Design Technology in Landscape Architecture

by

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ABSTRACT

THE PARAMETRIC PROCESS: A STRATEGIC ANALYSIS ON DIGITAL DESIGN TECHNOLOGY IN LANDSCAPE ARCHITECTURE

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Digital design technology is emerging in landscape architecture, however, there is a gap in design education and in practice regarding skills training and knowledge pertaining to digital design technology. The objective of this study is to investigate the efficiencies of using ‘parametric design’ for landscape designs and in the practice of landscape architecture. A comparative case study analysis of three landscape architecture practices who utilize parametric design was investigated, along with the creation of a questionnaire that was sent to key informants who specialize in parametric design, was used to evaluate the efficiencies and value of parametric technology. A 3D-model prototype was generated using Rhinoceros (Rhino3D) and Grasshopper to test the ‘parametric process’ against the ‘traditional’ analogue design process. This research is intended to determine whether adopting parametric technology into landscape designs can be so efficiently, while also serving as a precedent for further research in design technology.

Key Words: *parametricism, rhinoceros3D, grasshopper plug-in, generative design, computed design technology*

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LIST OF SYMBOLS, ABBREVIATIONS OR NOMENCLATURE

ADAM.. Automated Drafting and Machinery

AIA…………………………………………………..………. American Institute of Architects

AutoCAD.. Automatical Computer Aided Design

BIM.. Building Information Modeling

BLOB... Binary Large OBject

CAD……………………………………………………………... Computer Aided Design

CADAM……………………… Computer-Graphics Augmented Design and Manufacturing

CATIA.…………..………...... Computer-Aided Three-Dimensional Interaction Application

CPUs... Central Processing Units

ENIAC.. Electronic Numerical Integrator and Computer

ESRI.. Environmental Systems Research Institute

GIS... Geographic Information System

IBM.. International Business Machines

IT... Information Technology

M... Meters

NURBS.. Non-Uniform Rational B-Splines

PC... Personal Computers

SM.. Statue Mile

UNIVAC.. Universal Automatic Computer

LIST OF APPENDICES

1 Introduction

1.1 Overview

This work is an investigation of the value and perhaps efficiency of computational design, specifically parametric design in landscape architecture. The purpose of this research is to investigate and analyze the advanced design mechanism of the parametric process in landscape architecture as a means to support rapid design developments and to generate 'creative complex' design solutions from data. Apart of this goal is to evaluate the complex design tool based on its efficiency and innovation within landscape designs.

The current research that has been conducted on parametric design resides primarily in the fields of architecture and engineering. However, other research indicates that parametric design is emerging within the practice of landscape architecture. It is implied that digital technology is an innovative method of design communication, however, there is a need for improvements within the educational process and in practice regarding on how it can be adopted efficiently (Kara, 2010).

Currently, there a gap between skills training, application of knowledge, and utilizing the technology for parametric design not only in the studio environment, but also the in the working field (Schanbel, 2007). With technical and cultural interactions between humans and computers growing exponentially (Cantrell & Mekies, 2018), technology like parametric design has the ability to allow professionals to design beyond parameters.

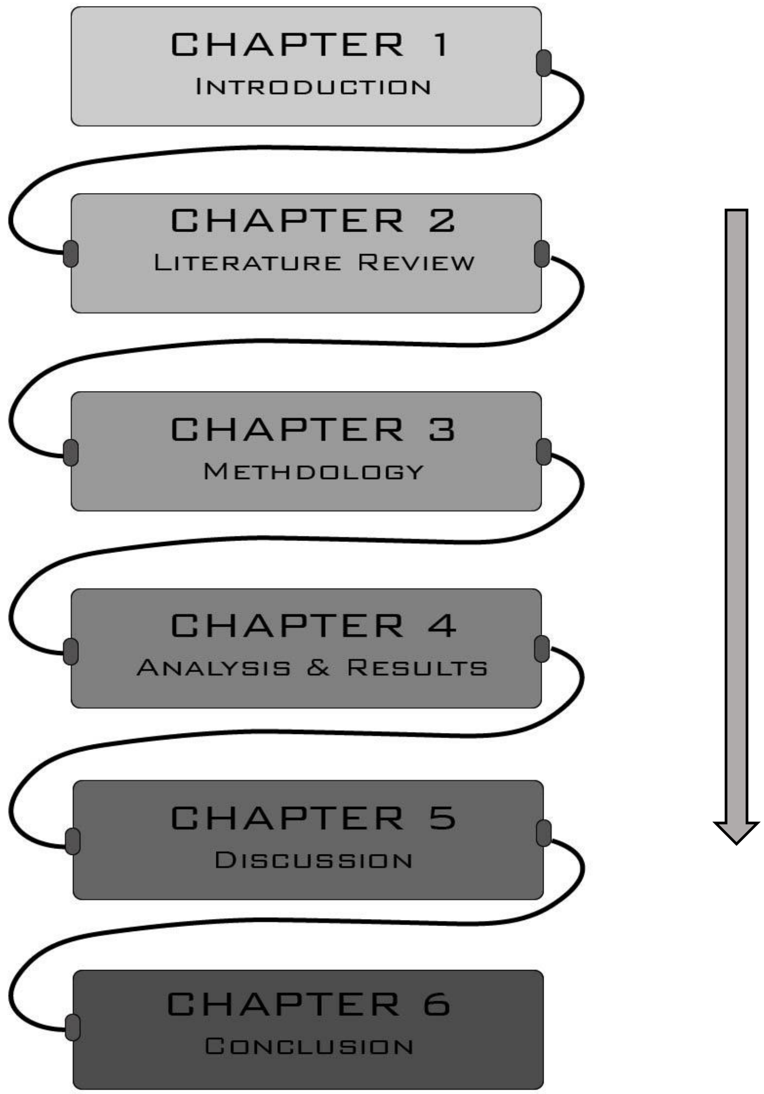

Figure 1-1 Thesis Structure. The aesthetic of the flow diagram is inspired by the parametric computer software 'Grasshopper' (Source: Author).

Figure 1-1 provides an overview of the thesis structure and how the research is organized. It is intended that this research serve as a case study for future development on the topic of parametric design in landscape architecture.

1.2 Research Problem

In landscape architecture, the advanced digital design mechanism of parametric design is present but is still slowly emerging. Research indicates that there is a lack in design education, specifically with skills training and application of the parametric technology in both the schooling process and in practice. Therefore, the problem that this research addresses is to evaluate the value and efficiency that parametric design offers within the design process and in the practice of landscape architecture as a whole.

1.3 Research Goal

The main goal of the research is to investigate parametric technology in terms of its versatility, efficiency, and innovation within both landscape design and landscape architectural practice. The topic of parametric design is complex; however, this research goal will contribute to a further understanding of the advanced digital design technology, specifically in the field of landscape architecture.

Furthermore, to achieve this goal, the following is a set of objectives:

1.4 Objectives

- To investigate landscape architecture through the idea of efficiency and to access new forms of complexity.

- To identify a critical strategy on how to adopt digital technology, specifically the parametric process, into the practice of landscape architecture efficiently.

- To create a questionnaire for key informants who use parametric technology in the practice of landscape architecture as a method of data collection.
- To evaluate three award winning case studies from landscape architecture practices where parametric digital technology has been utilized successfully.
- To create a prototype park design generated by the design software Rhinoceros with the Grasshopper plug-in to test the parametric design process using data and developed scripts.
- To evaluate the parametric process against the ‘traditional’ analogue design process.
- To ‘optimize’ digital design processes, while maintaining a sense of creativity; through the development of design ‘scripts’ for a series of site conditions.

2 Literature Review

2.1 Overview

This chapter contains a literature review of research pertaining to the topic of parametric design and digital technology. Each section of the review is broken into categories. The first exploring the definition of parametric design and technology. The second reviewing the history of computed technology. The third analyzing parametric design in a variety of architectural forms. The fourth on parametric design and technology in the field of landscape architecture. The fifth, the gap between education and practice. Finally, the efficiency of parametric design provides, along with its advantages and disadvantages.

The method chosen to review this topic was to analyze a variety of literature using key words such as *parametric, parametric design, landscape architecture, generative design, architecture, engineering, modeling, digital design, digital technology, computational design, design education, scripting,* and *design technology*.

As part of the methods process, a variety of literature was analyzed through the University of Guelph's Library, utilizing its online virtual library called Primo. This program provides a variety of peer reviewed literature that is accessible both on campus and off campus. With this program, key words were used to further search the topic. Other resources used to navigate the research was through books pertaining to the topics of parametric and generative design, coding, digital technology, landscape architecture, and architecture. To assert the structure of the literature review, instructions created by the University of Guelph's library (University of Guelph Library: Writing a Literature Review, 2019) were referenced to ensure the literature review would be sufficient to the university's guidelines.

2.2 Defining Parametric Design: What is it?

The concept of parametric design as a system, uses geometric modelling that encodes formal features, common to the design of its solution space (Granadeiro et al., 2013). To expand off Granadeiro et al., (2013)'s definition, the system specifically runs by explicitly defined algorithms that generate synchronically auditable forms and patterns (Çalışkan, 2017). The system utilizes its formal features as topological relations between the various parts of the designs and their dimensional variations (Granadeiro et al., 2013) Subsequently, the system is based on abstract definitions of possible design variations, which have the ability to display or produce design products (Fischer and Herr, 2002).

Parametric design is a complex system that uses algorithms as its foundation, which creates mathematical equations that encode different functions to manipulate design. The equations contain set variables that can take several forms and ranges. The variables control the alterations of the parameters of a design (Granadiero et al., 2013). Apart of these variables is the concept of coding or codification. Cantrell & Mekies (2018) define coding as a method "to express in syntax, a set of operations so as one or a system of computations may be made". Cantrell & Mekies (2018) simplify this definition by stating that coding acts as an organized collection of words, which when computed, establishes characters, actions, and context that delineate use or function. Cantrell & Mekies (2018) explain that the act of computing or "the computer" is to compile and interpret the code in the form of a narrative. Evidently, manipulating these codes is what sets the parameters of a design. As indicated by Granadeiro et al., (2013); Çalışkan, (2017); and Schnabel, (2007), it is agreed that parametric design offers a variety of advantages within digital design, however, its technique primarily is only adopted in the field and education of architecture and engineering.

A part of parametric design is generative form, a model composed of a set of computed rules that when applied, generate alternative designs (Granadiero et al., 2017). This is important factor in parametric design because generative form, or design, has the ability to design with variety. Its rules encode constraints to create only the intended output (Granadiero et al., 2017). Ultimately, it can establish a stylistic coherence and design identity while creating diverse designs (Granadiero et al., 2017). Ultimately, Granadiero et al., (2017) and Çalışkan, (2017) agree that generative design empowers the generative capacity of design by simulating endless potential solutions, such as complex pattern formations. Examples of complex forms can be seen in Figure 2-1. Figure 2-1 demonstrates the level of complexity generative modeling can take on for large-scale sites, specifically designing for responsiveness and productivity of landscape systems (Cantrell & Mekies, 2018). Granadiero et al., (2017) and Çalışkan, (2017) agree that by adopting parametric (generative) systems, it can legitimize designs. This allows designers to go beyond a range of design parameters. Figure 2-2, is an example of generative and associative modeling software. The software offers opportunities for the designer to customize their designs. Figure 2-2 is also an example of customized seating that is suited to adapt to a variety of body sizes (Cantrell & Mekies, 2018). Cantrell & Mekies (2018) explains that utilizing generative modeling allows designers the ability to set agendas for their designs. For example, the agenda set for Figure 2-2, encourages multiplicity and differentiation from the intimate scale of the human body to the expanses of the surrounding landscape (Cantrell & Mekies, 2018). Evidently, Cantrell & Mekies (2018) believes generative modeling brings forth advanced and innovative thinking in studios and professional offices. Generative modeling has enhanced a new generation of design techniques and fabrication technologies.

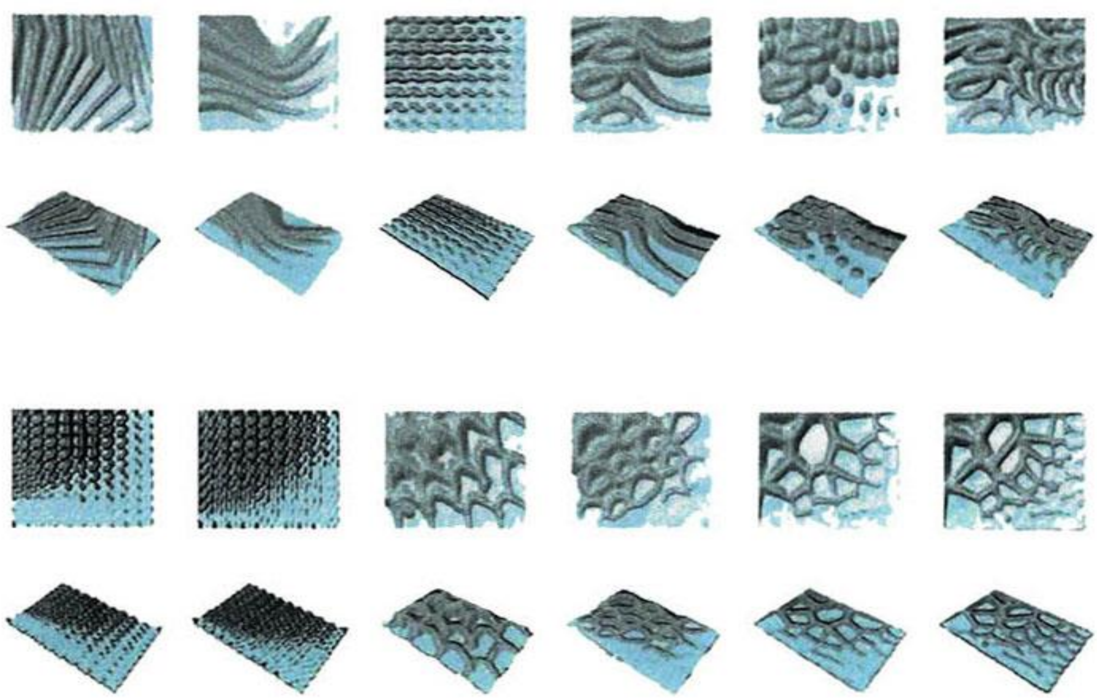

Figure 2-1 This image is an example of creative performative water landscapes using generative modeling to create complex forms. This project is Sonny Xu, Lanisha, Harvard Graduate School of Design. The instructors of this studio project are Chris Reed and Bradly Cantrell (Cantrell & Mekies, 2018).

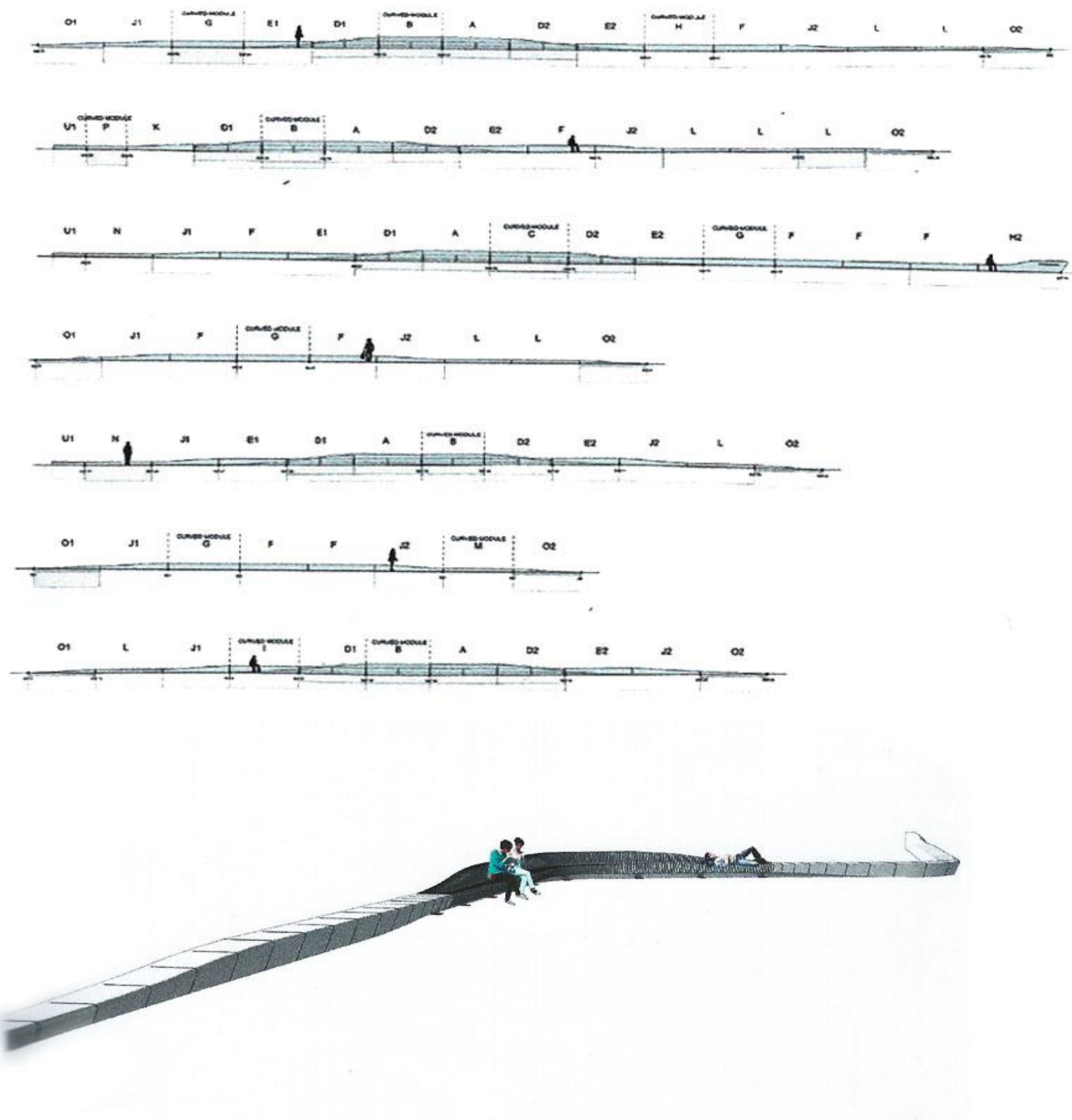

Figure 2-2 This image is an example of a series of elevations created through generative modeling. This demonstrates the models interplay of setting agendas of responsiveness, flexibility, and adaptability of designing custom benches. These images were created by the design firm Stoss for the Eda U. Gerstacker Grove, University of Michigan, Ann Arbor, MI, USA (Cantrell & Mekies, 2018).

Furthermore, parametric technology encourages designers to explore beyond traditional methods of design and allows for a type of innovative spatial thinking. The definition of parametric design has an advantage because among other design techniques, it indicates that the system can embody a variety of styles, thus supporting this idea of allowing designers to have more liberty when designing (Frazer, 2016). Frazer (2016), a pioneer and leader in revolutionizing computation and generative design, suggests that parametric design is in its second state and is being redefined as 'parametricism'. Parametricism opens up new possibilities, pertaining to scripting variational geometer, addressing a larger realm of social and environmental purpose (Frazer,2016). In concluding words, parametric design is driven through generative algorithms and has ability to design with diversified arrays of data sets (Cantrell & Mekies, 2018).

2.3 The History of Computational Technology

Computed technology has a significant history and would not be the unique system it is today without its long history of constant innovation. This section of the literature review will be investigating the history of technology and its impact on creating digital culture. Early computation can be traced to centuries before the Common Era, these straining from early Chinese, Babylonian, and Greek history (Cantrell and Mekies, 2018). The first written reference of the term "computer" dates back from 1613 where it was used to explain the definition of "one who computes", as someone who can compute in the theoretical sense (Cantrell and Mekies, 2018).

The history of computational design began primarily with automotive and aerospace engines, later innovating into computer technology and engineering. The first documented computer programing arose in 1843 where an analytical engine was created by Charles Babbage, a British mathematician and scientist (Cantrell and Mekies, 2018; Frazer, 2016). This was the first engine of its time to be generated from computed algorithms (Frazer, 2016; Cantrell and Mekies, 2018). Other large scale electronic-computing experiments were created during World War II. These included mechanical calculating machines, human computing projects, and analogue electric cybernetic control systems (Ensmenger, 2012). However, Cantrell and Mekies (2018) suggest that the foundation of the modern computer was established by Alan Turning in 1937, where he presented his seminal paper on “Computable Numbers”. Turning established the idea of today’s contemporary culture, that the use of a machine (the computer) can be used to complete human tasks.

With Turning’s theory in mind, during the post war period, society starts to see a shift in technological trajectory. Specifically, Ensmenger (2012) expresses that we faced our own “Cambrian explosion” of technology where society began to view computed technology not only as a technical tool, but also with having cultural and social significance. During this period, we start to see entire industries devoted to information and data processing. Industry firms included in this are IBM, Burroughs, Honeywell, and Remington Rand, which as Ensmenger (2012) explains, play a significant role in the early computer industry.

By the 1950s computerized technology became available to the public. Specifically, in 1951, the Universal Automatic Computer (UNIVAC), was the first commercially available computer system in the United States, created by J. Presper Eckert and John Mauchly, the founders of the electronic numerical integrator and computer (ENIAC) (Butterfield, 2016). In 1955, the preferred device arithmetic was the Comptometer (Ceruzzi, 2003). This device was manufactured by Felt and Tarrant of Chicago as a key-driven machine to perform mathematical calculations. It could calculate addition and subtraction every few seconds, however, it could not multiply or print the results of the calculations (Ceruzzi, 2003). Throughout the 1950s, we start to see the architecture of computers evolve to incorporate scientific applications such as incorporating more storage and voluminous input and output operations (Ceruzzie, 2003). In 1959, core memory was created to boost computer performance, this evidently became a more cost-effective application for several commercial systems (Ceruzzie, 2003). By the 1960s, we start to see the emergence of computed design technology, the origins of digital design (Cantrell & Mekies,2018).

2.3.1 The Pioneers of Early Design Technology

Frazer (2016) expresses that Ivan Sutherland's, a pioneer of digital design, Sketchpad system, created in 1963, is an example of being of the earliest computing technologies of parametric design for architecture. It is one of the earliest experiments in computer graphics, specifically, the device's software allows the user to create drawings and to store them (Clayton, 2005). The Sketchpad made it possible for humans and computers to converse swiftly, evidently improving productivity

(Sutherland, 1980). Figure 2-3 demonstrates how the device is used. When the user applies the light pen, similar to traditional drafting equipment, the user places the pen directly onto the screen to position parts on the drawing. Knobs, as shown in Figure 2-3, are turned to manipulate and control the drawing functions shown on the display screen (Sutherland, 1980). The system contained input, output, and computation programs which enable it to interpret information drawn directly onto the display screen (Sutherland, 1980). The Sketchpad was used to draw mathematical, scientific, mechanical, electrical, and animated drawings (Sutherland, 1980). However, the Sketchpad has proved to be the most useful in understanding processes such as the motion of linkages, which can be described with using pictures (Sutherland, 1980). The Sketchpad could also print drawings onto paper using a plotter system, Figure 2-4. Using the TX-2 operating system controlled the plotter to draw straight lines and circles (Sutherland, 1980). The Sketchpad is a predecessor to early computers specifically for design and is known to be the first computer to speed up the calculations of any parametric equation.

Figure 2-3 This is an image of a designer using the TX-2 Operating System demonstrating the Sketchpad in use. The designer is using the light pen to create drawings projected onto the screen. To control the functions of the drawing, toggle switches are used, see knobs below screen (Sutherland, 1980).

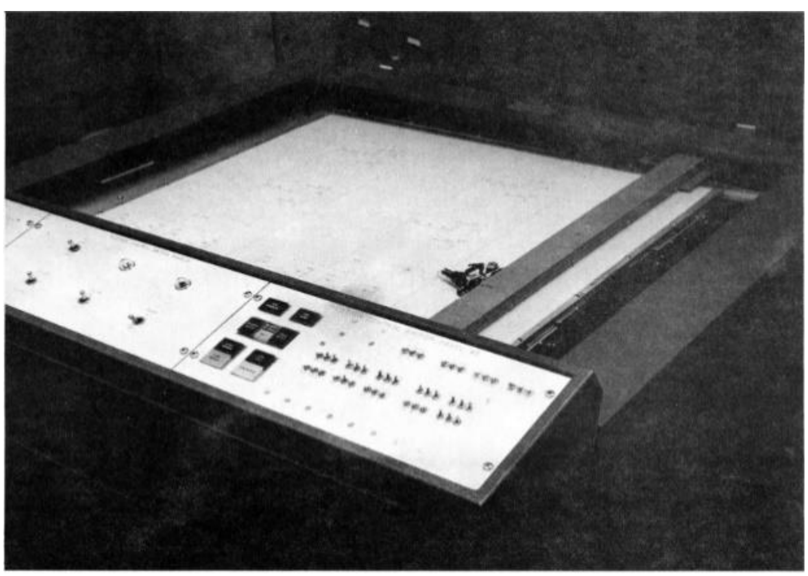

Figure 2-4 Sketchpad used with printing plotter. Used with Sketchpad or off-line using punched paper tape (Sutherland, 1980).

In 1965, Lockheed Martin Corporation, a company who focuses on aerospace and defense technology, create the Computer-Graphics Augmented Design and Manufacturing (CADAM) software. The CADAM software was created as an internal mainframe application within the company (Weisbery, 2008). The CADAM software was then implemented onto IBM computers, specifically the IBM 360 computers using IBM's 2500 graphics display terminals, see Figure 2-5 (Weisbery, 2008). The system was dedicated to computer graphics and utilized the CADAM software as a means to achieve optimum productivity (Weisbery, 2008). These design terminals (Figure 2-5) produced over 400,000 electrical diagrams using the CADAM software, and at one point, were producing drawings every 15 minutes (Weisbery, 2008). By 1971, CADAM had become commercialized. Although expensive, it was reported by customers that CADAM had significantly increased productivity, finishing projects that originally were projected to take 18 months with a crew of 70 workers to 12 months with 40 workers (Weisbery, 2008).

Figure 2-5 The IBM 360 Computers with the 2500 graphics display terminals, located at Lockheed Engineering Department (Weisbery, 2008).

In the 1970s, we start seeing the emergence of 3D software's, specifically for engineering purposes. In 1977 Dassault Aviation, a French software company creates the computer-aided three-dimensional interaction application (CATIA) software (Bernard, 2003). CATIA was created to develop the external parts of airplanes, specifically rendering 3D shapes for the external curves, surfaces, and volumes (Bernard, 2003). Dassault Aviation worked closely with IBM to sell and support CATIA worldwide (Bernard, 2003). Between the years of 1967 to 1981, Dassault continued to innovate the CATIA software by focusing on integrating better computer aided design

(CAD) and CADAM applications into CATIA (Bernard, 2003). CATIA was a leader in drafting, 3D solids and robotics during this time (Bernard, 2003).

Markus (2010) believes that the 1980s had some of the greatest advancements in early computed design technology, specifically data bases, emailing, and central processing units (CPUs) were beginning to emerge. In 1982, John Walker, a computer programmer and founder of Autodesk, released the first version of AutoCAD, making it the first CAD system available for personal computers (PC) (Cantrell and Mekies, 29018). During that same year, Jack Dangermond's ESRI launched Arc/INFO, the first geographic information system (GIS) platform available commercially (Cantrell and Mekies, 2018). The origins of the AutoCAD software can be dated back to the 1970s when the Automated Drafting and Machinery (ADAM) software was created. The ADAM software reflects about 90 percent of today's commercial computed software, this including the AutoCAD software (Autodesk, 2019).

In 1985, Autodesk releases their next innovation, AutoCAD 3D which revolutionized digital design software's (Autodesk, 2019). Along with AutoCAD 3D, we see innovative design solutions with Building Information Modeling (BIM), a 3D model-based process for architecture and engineering, and in digital prototyping (Autodesk, 2019). Specifically, in 1986, Robert Aish coins the phrase 'building modeling', with this, early BIM programs were beginning to be used for large scale projects (Autodesk, 2019). The 1990s showed the transformation of adopting the World Wide Web and open-Internet standards, a revolutionary upgrade to the world of computed technology (Markus, 2010).

From the early 2000s to present time, AutoCAD has released a variety of features to further innovate the software into the design industry (Autodesk, 2019). One of BIM's revolutionizing upgrades was in 2004 where Autodesk created a software that allowed collaborative working under one dynamic model (Autodesk, 2019). This meant that all those involved in a project (engineers, architects, landscape architects, and builders) could work together using one dynamic model that updates changes as the project progresses. It is acknowledged by both Frazer (2016) and Markus (2010) that the fast development within technology has had an impact on organizational practice, specifically with keeping up to date with its exponential flux of innovation.

2.4 Parametric Design in Architecture

The development of computed aided design technology continues to innovate and inevitably has had an impact on the engineering industry. However, the presence of parametric design can also be seen throughout the history of architecture in a variety of forms. This section of the literature review is an analysis of different forms and responses of parametric design used for architectural purposes.

2.4.1 Free Form Parametric Architecture

Parametric design encodes and clarifies the relationship between design intent and design response. This can be noted by parametric precursors, Antonti Gaudi and Frei Otto (Gallo and Pellitteri, 2018). Gaudi was a Catalan architect known was his unique individualized free flowing design work, often inspired by nature's natural forms. Otto was a German architect and engineer known for pioneering tensile and membrane architecture. Both Gaudi and Otto are masters who have offered unique insights into their work as great geometric and parametric thinkers (Burry, 2016). Gaudi's career designs from 1900-1914 to Otto's studio designs during the 1960s and 1970s share several similarities in thinking (Burry, 2016). Specifically, both Gaudi and Otto share the idea of using 'flexible models' to work with 'freeform' (Burry, 2016).

Early forms of parametric architecture can be noted by Gaudi, specifically with his works for the Colònia Güell Chapel, Barcelona. Gaudi experimented with his 'hanging model' (Figure 2-6) for designing the chapel. Figure 2-6 demonstrates his strategy of determining the architectural form of his design. Gaudi adopted a self-generating process that was performed on a physical model (Figure 2-6). He used weights on strings to serve as an upside-down version of the arched forms he sought (Wendland, 2000). With this experiment, Gaudi was able to analyze the angles that fell, study them fluidly and to use them to generate architectural forms (Wendland, 2000).

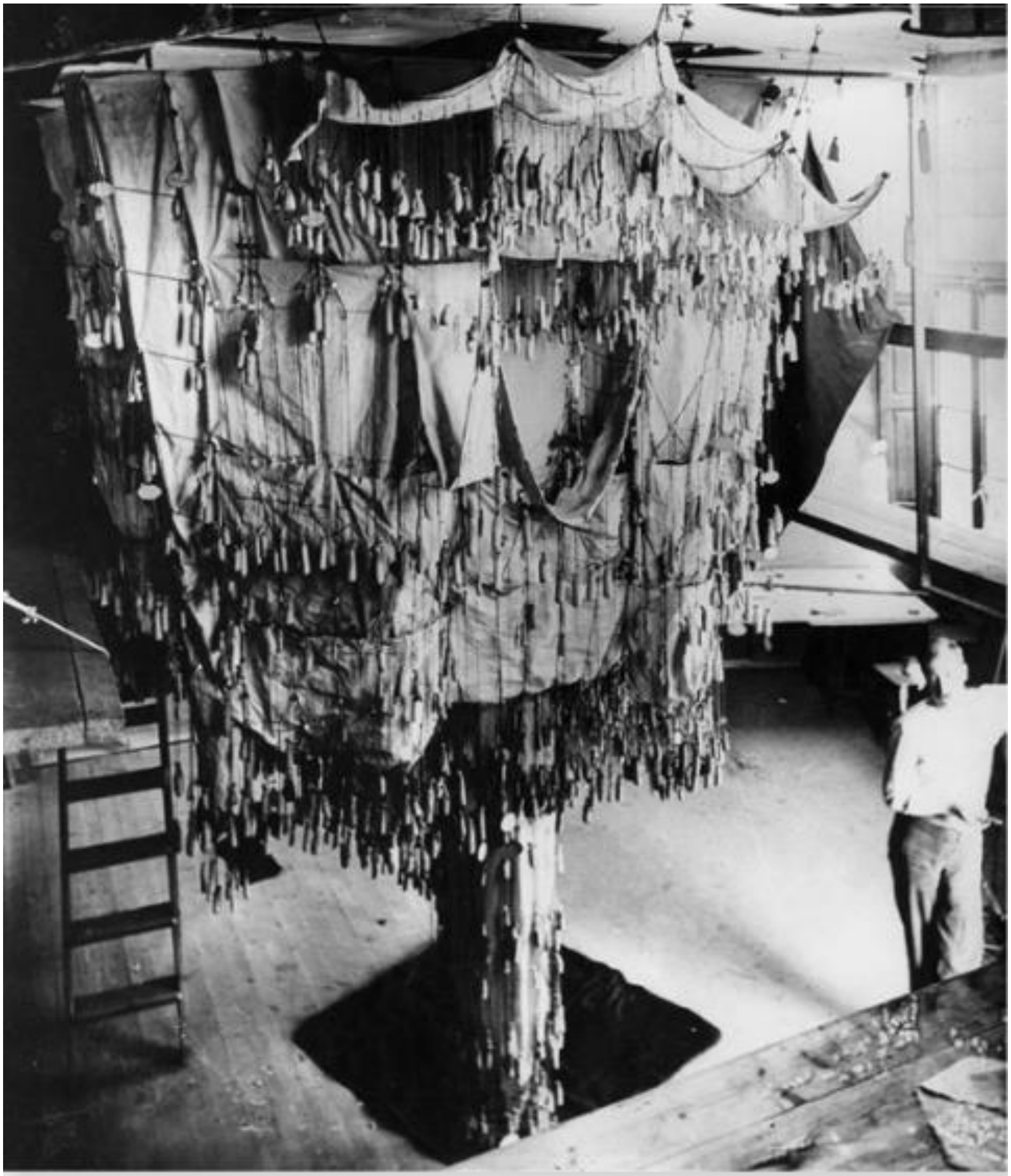

Figure 2-6 Antoni Gaudi's "hanging model" experiment used to define architectural form (Burry, 2016).

Otto used similar approaches to Gaudi by deriving structures from simulation models. Otto systematically developed strategies based on self-generating processes that are performed on the physical models (Wendland, 2000). However, his approach on the self-shaping process was assumed to be found in nature, specifically creating pneumatic structures (Wendland, 2000). Otto explains that the process essentially is to be a natural one and therefore, suggesting that the architectural shape of a building is not subjected to the designer, rather it is justified by the self-shaping process, see Figure 2-7 (Wendland, 2000).

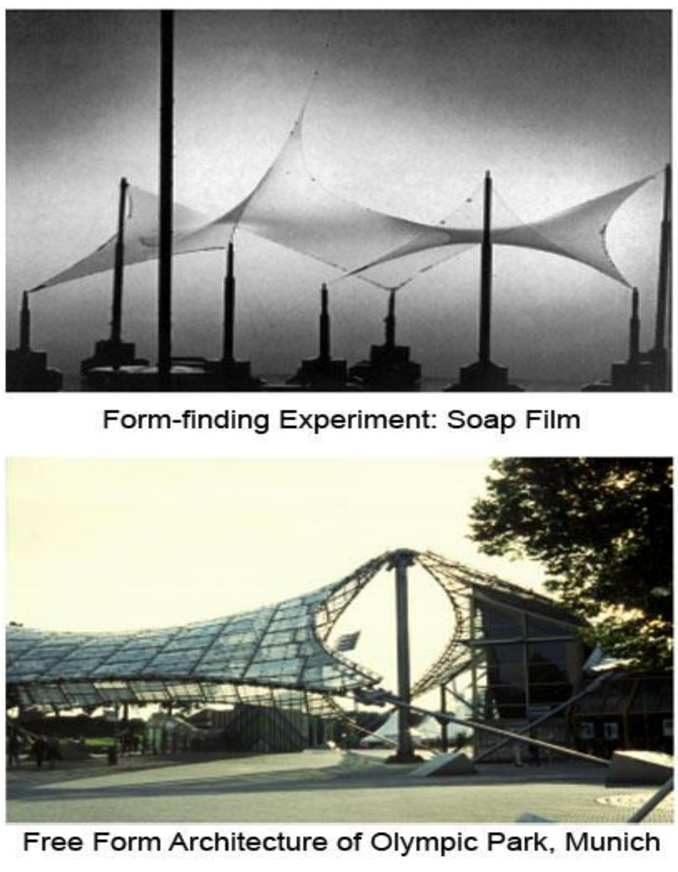

Figure 2-7 These images are of Frei Otto's self-shaping model process for Olympic Park, Munich (1972). The image (left) demonstrates the form-finding of a small tent using soap film. The image (right) shows the end result of the architecture produced for the park (Wendland, 2000).

2.4.2 Biophilic Parametric Architecture

Another design approach that is often correlated with parametric architecture is biophilic design. Biophilic design is a form of biomimcry, which utilizes the use of biological forms (Eren et al., 2018). It often reflects the relationship between humans and nature. In terms of desiging with architecture or perhaps landscape architecture, the designs often resonate from social, technological, religious, and economic conditions within nature (Eren et al., 2018). Subsequently, with having technological advancements available, such as parametric design, designers can create forms and shapes that imitate nature. Utilizing parametric design has the ability to experiment and construct better design solutions due to the technologies innovative and quick responses.

A research-based urban design, landscape and architectural firm called TerreformONE explores innovative technology to identify design solutions for creating greener and efficient designs (Amoroso, 2012). Figure 2-8 is a project example from TerreformONE called, Fab Tree Hab: Living Graft Dwellings. This project is an example of utilizing parametric technology to achieve a biopilic result in architecture. The design is an example of biophilic living by creating tree-house living designs that are sustainable, edible, and economical (Amoroso, 2012). As shown in Figure 2-8, prefabricated templates are created using parametric 3D files. The technology can easily interpret the phasing of the design process and vegetative development. This gives designers greater clarity during the design process on how the end result will form.

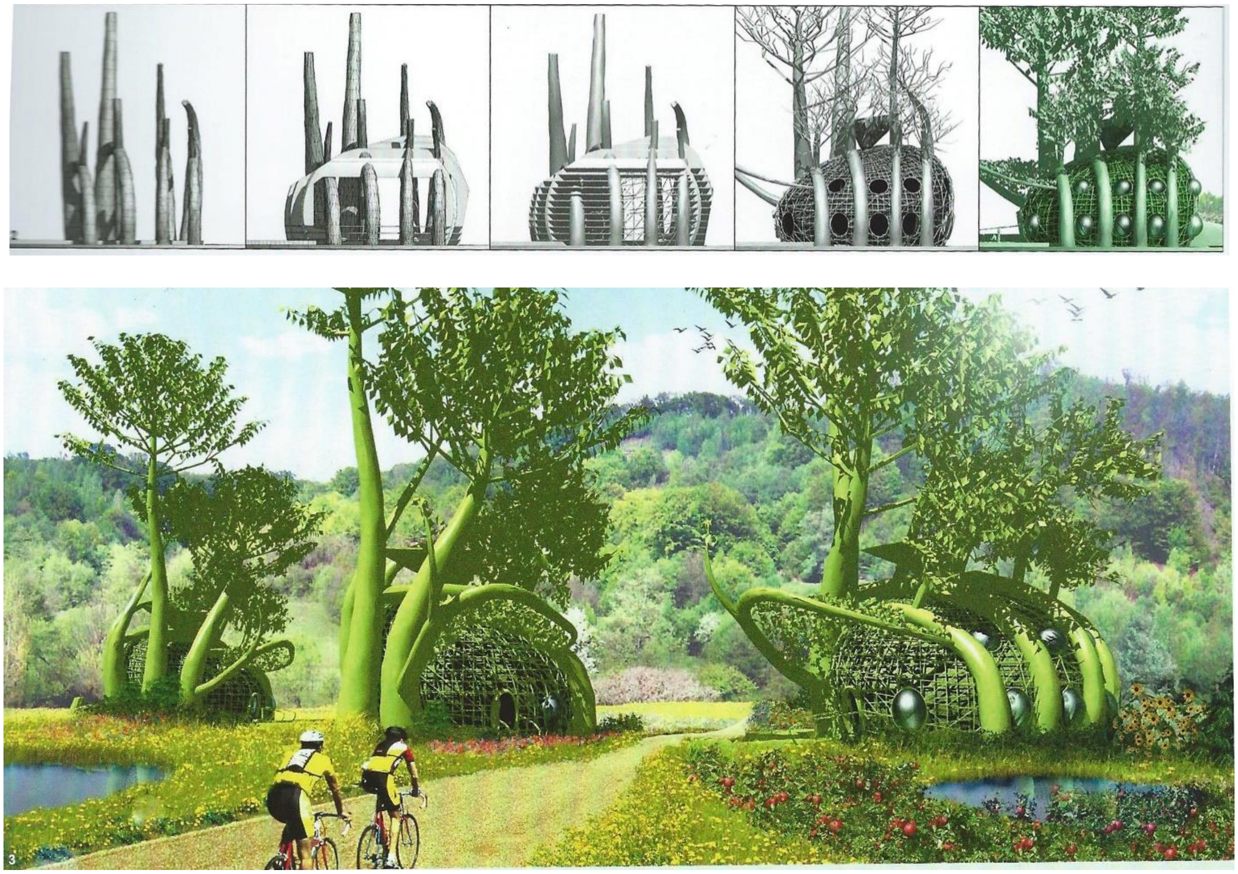

Figure 2-8 Sustainable tree-house living. The image (top) is a representation of design phasing by utilizing parametric 3D modeling. The image (bottom) is a rendering of the final product. This project is called Fab Tree Hab: Living Graft Dwellings created by Terreform One (Amoroso, 2012).

This process is also noted by the architectural and urban design studio, ecoLogicStudio with their project, SuperTree. This project is an architectural apparatus that mimincs the form of a tree (Figure 2-9) into a high-resolution, productive photobioreactor that has the ability to connect the human metabolismto proliferation of life within micro-alagae (ecoLogicStudio, 2018). This is an extrodinary project that integrates environmental processes of nature into a complex innovative design.

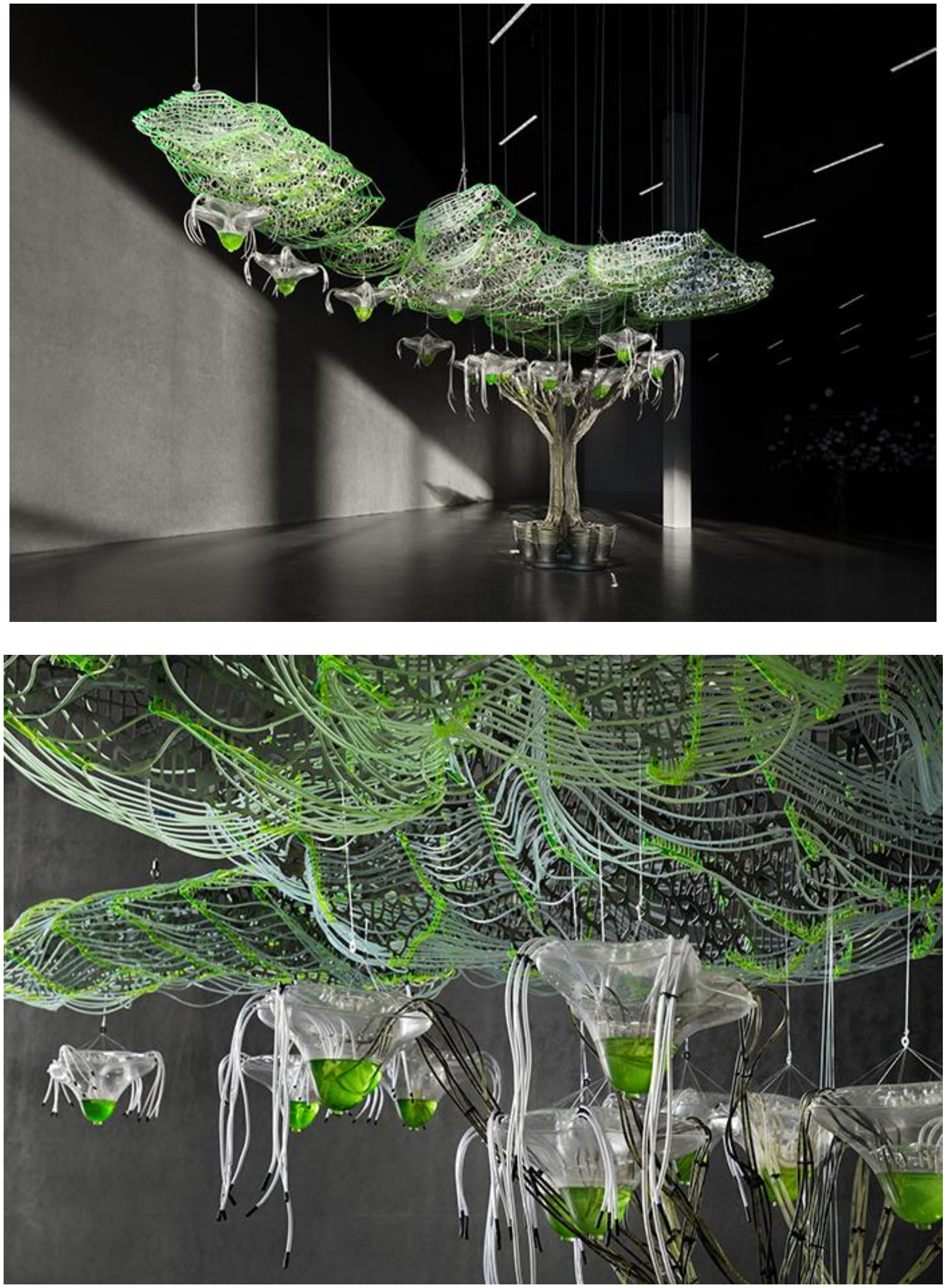

Figure 2-9 Image (left) the SuperTree project is an example of an augment version of the biosphere created by ecoLogicStudio. Image (right) is the tree canopy powered by colonies of cyanobacteria (ecoLogicStudio, 2018).

2.4.3 ‘Blob’ Architecture: ‘Blobitecture’

A unique design approach in parametric architecture is ‘blob’ (binary large object) architecture. Greg Lynn (2004), a key figure in contemporary ‘blob’ architecture, expresses that ‘blobs’ suggest alternative strategies for structural organization and construction for architecture, specifically by enhancing new complex forms. Lynn (2004) explains that ‘blob’ construction is in its infancy stage of development in contemporary architecture culture, however, it has the ability to interpret new discourses for design. Lynn (2004) advocates that ‘blobs’ are a model of natural form that is calculus-based. To achieve ‘blob’ form, digital tools such as parametric technology can be used.

In Figure 2-10, the ‘blob’ appears to have organic form and is free-flowing. Lynn (2004) explains that the structural members of the design’s structural system is similar throughout but not identical. Evidently, Figure 2-10 is an example of ‘blob’ architecture demonstrating repition pattern. However, with each repition of the homogenous surface, each surface brings forth a slight flucation or differentation (Lynn, 2004). This result strains from the innovation of parametric technology, where algorithmic thinking can encode slight variability to a design.

Figure 2-10 The Sage Gateshead Concert Theatre, UK, designed by Foster and Partners. An example of parametric ‘blob’ architecture (Proto-Knowledge, 2011).

‘Blob’ architecture is influenced by the shapes and forms of nature. Lynn (2004) expresses that architects often look to nature to justify the beauty of architecture, similar to the ideas of biophilic design. Evidently, Lynn (2004) suggests that the forms of ‘blobs’ or ‘blobitecture’, Lynn’s coined term, often mimic the organic shapes of bulging, celluar, or amoeba-like expressions. Furthermore, parameticism, architecture created by utilizing algoriths to define shape and form, is present in ‘blob’ architecture. The innovation of parametric technology allows designers to design with variability and to design beyond parameters. The technology invokes a new form of thinking that goes beyond traditional analogue methods.

2.4.4 Responsive Landscapes: Responding to Climate Change

Designing for architecture generally focuses on the responsive interactions between a space and the people who use it (Cantrell and Holzman, 2016). However, society is seeing an up rise in changes to our environment. For instance, climate change is a prominent subject that will impact designers such as architects and landscape architects. Evidently, this is putting pressure on architects to become adaptive to environmental changes, specifically, to be responsive to the changing landscapes (Cantrell and Holzman, 2016). Cantrell and Holzman (2016) express that architectural technology is not adaptable for the on-going changes of ecological systems. However, the foundation of the landscape architecture profession is built upon designing for responses and the regeneration of natural systems (Cantrell and Holzman, 2016). This thought could suggest that further integration of parametric technology into the profession of landscape architecture could pose promising results.

Cantrell and Holzman (2016) explain that the term ‘responsive’ implies that an object engages in a process of feedback, a communication between two actors. Responsive technologies, such as parametric software’s, increase accessibility for designers. It has the ability to promote the development of new design methodologies and promotes to create beyond conventional methods (Cantrell and Holzman, 2016). Zhang (2017) explains that factors need to be considered in developing and conceptualizing responsive landscapes, specifically human factors. Zhang (2017) suggests that designers can experiment with and study human behaviors through simulation interactions between people and the proposed landscape. The convenience of responsive technology encourages designers to design accordingly to different scenarios prior to completion of a project (Zhang, 2017).

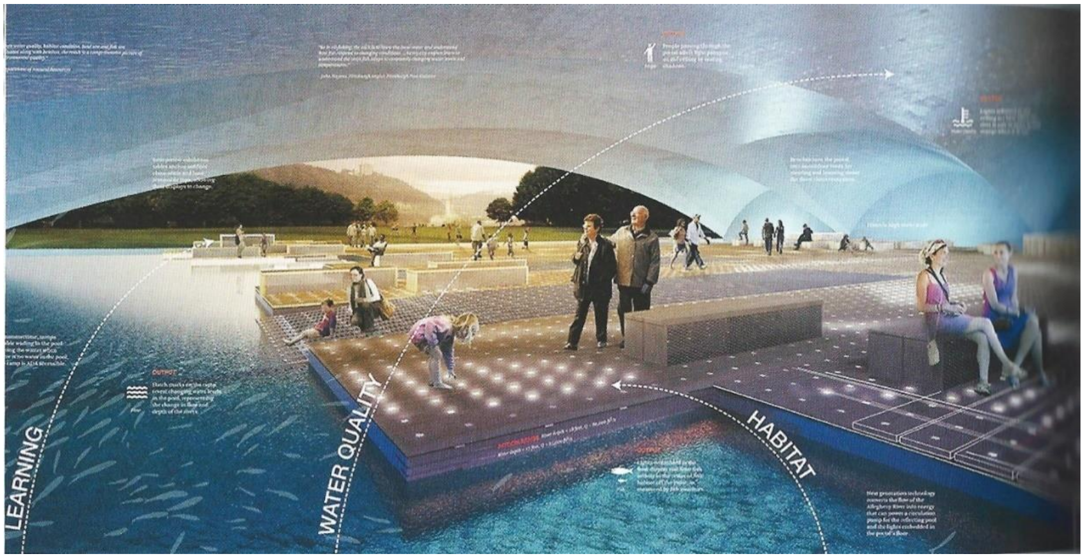

Figure 2-11 The image is a rendering visualization of the complex environmental series of overlapping events, by SCAPE/LANDSCAPE ARCHITECTURE and The Living, New York, 2011. (Cantrell and Holzman, 2016).

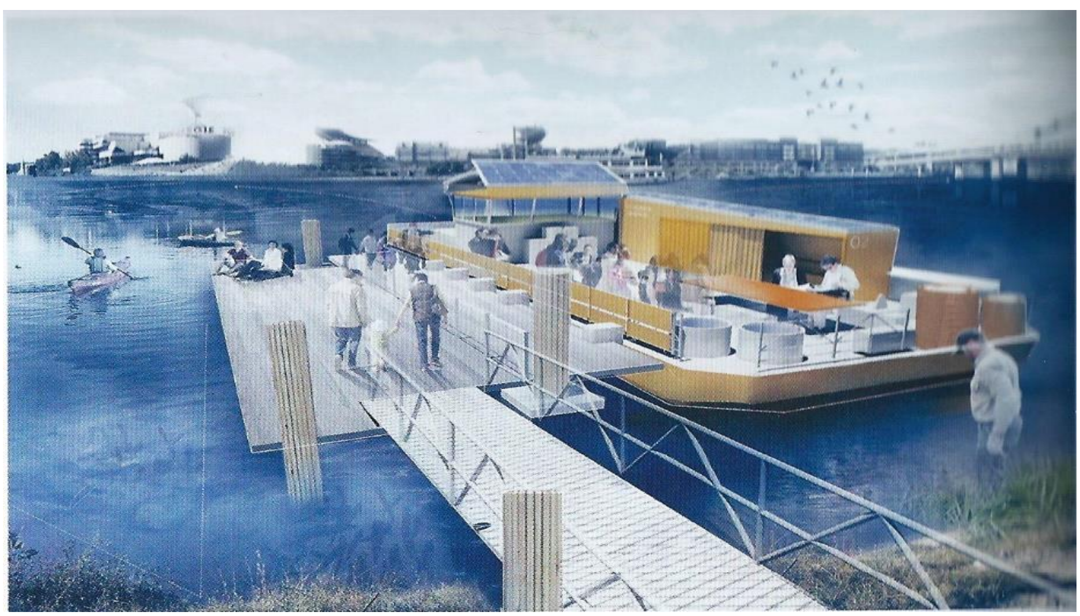

Figure 2-12 The image is a rendering visualization of the proposed eco-barge and Children's Science Museum by, SCAPE/LANDSCAPE ARCHITECTURE and The Living, New York, 2011 (Cantrell and Holzman, 2016).

Figure 2-11 and Figure 2-12 are examples from a proposed project for the Pittsburgh's Point State Park. The proposed project location is in an underutilized spaced located at the underpass of the park's Duquesne Bridge. The space is projected to be rejuvenated as a learning landscape in response to climate change. The project visualizes four major processes within the park, water quality, fish flow, people flow and river flow (Cantrell and Holzman, 2016). This project was created by two firms, SCAPE/LANDSCAPE ARCHITECTURE and The Living, to illustrate the natural processes through both physical and virtual visualizations of environmental phenomena's (Cantrell and Holzman, 2016).

The Pittsburgh Point State Park example demonstrates how designers can utilize innovative responsive technology to propose scenarios for a variety of events. Responsive technology, such as parametric software programs, allow designers to think beyond present time and to design in a way that encompasses all beings, both human and the environment.

2.5 Parametric Technology in Landscape Architecture

As mentioned above, there is a strong history of parametric design within architecture and engineering (Çalışkan, 2017 and Kara, 2010). In terms of the practice of landscape architecture, advanced digital computed technology is beginning to emerge. Evidently, modern digital design technology is playing a role in visual representation. For instance, Ervin (2001) explains that digital technology is being used to create landscape models as a method of visual inference. These models act as a simulation, and understanding for invisible aspects of landscapes (Ervin, 2001). Ervin

(2001) believes that these models are a standard technique for convincing a static visual representation, however, its representation is still in its infancy. Walliss and Rahmann (2016) in agreement with Ervin (2001), expresses that landscape architecture currently demonstrates a more tentative engagement with digital technology. Walliss and Rahmann (2016) suggest that this is due to many landscape architects having difficulty in conceptualizing digital technology. To expand, Walliss and Rahmann (2016) suggest that this issue stems from being able to conceptualize creativity as a human endeavor, designers are hesitant to stray away for analogue design techniques and fear that digital technology will distort reality. Evidently, Ervin (2001) and Walliss and Rahmann (2016) agree that although digital technology is present in landscape architecture, it still has a long way in terms of its technology and adaptation into the field.

2.5.1 Traditional Versus Digital

Pihlak (2004) expresses that between the 1980s to 1990s, landscape architects and designers have faced challenges in terms of adopting new design techniques. Pihlak (2004) explains that the majority of today's landscape architects and students continue to use traditional computer-aided drafting software's dating from the 1960s to 1970s. These software's included updated versions of AutoCAD, Vectorworks, and Sketch-Up. Cantrell and Michaels (2010) agrees with Pihlak (2004) in that traditional analogue design techniques are highly used presently.

Taylor (2006) makes reference to Palmer (1996) where a study was conducted in 1996. This study has analyzed the use of computers in practice by landscape architects.

Palmer (1996), found that over half of the landscape architects sampled in his study had no AutoCAD skills and that 70% had limited or no access to the internet. About 90% of those same landscape architects sampled had little to no experience with GIS (Geographic Information Systems) and 3D-modeling software's (Palmer, 1996). Although computers were available commercially, it seemed that only specialized studios were adopting the innovative computed technology (Cantrell and Mekies, 2018). With this information, it appears that there was a gap in skills training with digital computed technology.

Cantrell and Michaels (2010) argue that traditional analogue design techniques also play a vital role in understanding the application of digital tools. They believe this is something we should not stray away from. Evidently, both Ervin (2001) and Pihlak (2004) suggest that digital technology is current, specifically in the architectural field. However, in terms of landscape architecture, research in the field is stalling and lacks progression (Ervin, 2001; Pihlak, 2004). In opposition to Pihlak (2004), Cantrell and Mekies (2018) argue that digital design is innovative and is providing a model of transition for the practice. Cantrell and Mekies (2018) believe that computation technology gives designers the opportunity to test and experiment with complex designs and the social systems associated with them. Although the technology is still emerging into the practice, it does allow opportunities for designers to evaluate their ideas more thoroughly throughout the design process.

Pihlak (2004) again reiterates how the current technology standard lacks visual and emotional qualities of output. Ervin (2001)'s argument agrees with Pihlak (2004) in that representations of basic landscape elements, for example, terrain, water, and vegetation, are simply displayed. Evidently, Pihlak (2004)'s statement reinforces that there is a need for improvement in digital design. Ultimately, their arguments further support that more research in digital design, perhaps with parametric technology, could revolutionize digital representations in landscape architecture.

Other research, by Monedero (2000), explains that the architectural and engineering fields have excelled in the development of computer-aided technology, specifically with the software's BIM and AutoCAD's Revit. To contradict Ervin (2001) and Pihlak (2004), Monedero (2000) suggests that innovative computer-aided drafting software's are advancing too rapidly, and rather they have been designed in a way that are not useful for designers. Specifically, Monedero (2000) argues that they can produce aesthetically advanced looking designs, however, they are not user friendly. Monedero (2000) notes that as a designer, constant revision is common, however, the current computed technology does not produce architectural forms that are suitable for revisions.

2.5.2 The Design Process: Where Does Parametric Technology Stand?

Schnabel (2007) suggests that parametric design techniques should be adopted into the design process during the earlier stages. Schnabel (2007) believes they offer obvious advantages. Zhang et al., (2019) agrees with Schnabel (2007) in that parametric technology offers advantages, specifically during the early design stages for achieving optimum performances on design scenarios. Mondero (2000) argues against this suggestion and instead believes it is a mistake to try and advance a design too quickly with parametric technology because he believes it is not adequate enough for representing what is needed in design. Evidently, perhaps more research on how effective parametric design techniques are on architectural and landscape architectural designing is needed.

2.6 Digital Design: The Gap between Education and Practice

This section of the literature review will be focusing on the topic of digital technology education in the realm of design schooling and whether it is being filtered efficiently into the design industry, specifically the practice of landscape architecture. Schnabel (2007) expresses that there is a gap between skill training in the field and the application of knowledge within the studio environment. Fischer and Herr (2002) agree with Schnabel (2007) in which they recognize that in the emerging educational field of digital technology, it currently lacks methodologies, teaching experience and introductory study material for students. Schnabel (2007) again emphasizes that design studios are an essential learning environment for design students. However, Schnabel (2007) asserts that in terms of learning digital techniques for design, tensions are apparent, because sufficient training in the software's is needed. Cantrell and Michaels (2010) emphasize that professions of landscape architecture and urban planning hold a strong tradition of representation that continues to evolve with the professions. Cantrell and Michaels (2010) also explain that during the past hundred years, analogue representation, such as pencil sketching, ink, markers, and watercolour, have been the prominent method of design representation. However, Cantrell and Michaels (2010) agree with Schnabel (2007) that there is a fundamental gap between the analogue and digital tools used to represent landscape architecture and urban planning projects.

Erlendsson and Erk (2012) professors at the Izmir University of Economics Architecture program created a studio project in 2009 where a 15-week studio-based project on “Temporal and Urban Peripheries” was conducted. Their focus was to incorporate parametric architectural design into the project using Rhinoceros NURBS modeling and its Grasshopper plug in as their digital component. Rhinoceros 3D, also called Rhino3D, is a 3D modeling software. This software offers non-uniform rational basis spline (NURBS) capability, which provides offers greater flexibility for complex modeling. It was developed by Robert McNeel & Associates in the early ‘80s. Its Grasshopper plug in provide parametric capability. Erlendsson and Erk (2012) argue that the earlier a designer becomes a "digital craftsman”, a new way of thinking and communication is established, and the tools become more of an idea generator. However, Erlendsson and Erk (2012) agree that digital technology is not to replace traditional methods of design, rather it should encourage designers to use the logical concept of “systems thinking” to develop projects. Once proficient in these skills, Erlendsson and Erk (2012) suggest that it allows for a greater understanding of the nature of digital design. Erlendsson and Erk (2012) express is that the students have gained a greater understanding and skills in digital design technology. However, Schnabel (2007) contradicts Erlendsson and Erik (2012) and instead believe that the integration of digital knowledge into design courses often fails. Schnabel (2007) argues that when students are too focused on acquiring these advanced skill-sets, it often prevents a deeper understanding on design and its theoretical concepts.

Kara (2010) argues an interesting perspective, incorporating both Schnabel (2007) and Erlendsson and Erk (2012)'s arguments in that educating in practice can hinder creativity, rather students would excel more from gaining experience through a practitioner in the field. By pairing them with inexperienced students, this provides the "survival of design education" as a form of knowledge base for newly graduated students (Kara, 2010). An interesting point that Schnabel (2007) expresses is that digital skill-sets often are lost due to semester-based learning. Evidently, students who stay updated on these skills on their own time are able to bring them into practice once completing their education. Evidently, the studio environment is good for theoretical based learning, however, acquiring advanced digital software skills can be difficult.

Love (2009) argues another perspective to the gap issue. Love (2009) agrees that there is a crisis and tensions in design education. However, Love (2009) expresses that there is a contentious divide on younger faculty who favour parametric modeling and the student body who demand design studios that prioritize social relevance and environmental stewardship. Specifically, Love (2009) explains that parametric modelling or digital scripting programs have dominated design discourse at universities like Yale, Harvard, Princeton and Columbia. Evidently, Love (2009) suggests that this is due to the increasingly large influences of parametric practitioners such as Greg Lynn, Preston Scott Cohen and Monica Ponce de Leon have on the newest generation of assistant professors. These architects are influential and highly regarded academics, theorists and practitioners in the field.

However, Love (2009) argues at the opposite end of the ideological spectrum that there are comprehensive studios that avoid formal experimentation such as the parametric process. Love (2009) believes this is because there are attributes applied to architects regarding their proper cultural role is to be advocates for sustainable design, in terms of the international debate on climate change. Subsequently, this ideal has led to the American Institute of Architects (AIA) to ensure that the list of required topics for education in architectural programs is to focus on sustainable design with an emphasis on renewable energy and consumption of buildings (Love, 2009). For now, Love (2009) believes that there is a need to better understand the complexities and pressures of mainstream practices. Specifically looking at how existing professional power structures, who work with real clients and use regulatory frameworks, encourage new and innovative design productions such as parametric design and how they inhibit other methods (Love, 2009)?

Further research is needed to see how landscape architecture practices are adopting parametric technology into their professional structures and whether it is being implemented efficiently. It is apparent that in some cases digital computational skills are being taught during the education process, however, other research suggests that advanced software programs hinder the student's learning abilities in other areas. Furthermore, we are faced with this gap between education and the practice of landscape architecture in which some students are better prepared than others. In the current research reviewed for this thesis paper, it is evident that more research is needed in the topic of digital design, specifically parametric design within landscape architecture. This is still a relatively new subject in the landscape architecture field.

2.7 Parametric Design: Efficiency

Although the process of using parametric technology can appear to be complex, the application of utilizing the tool can be efficient. Fu (2018) believes the parametric process to be a resilient one. Specifically, Fu (2018) explains that the technology allows designers to quickly, easily, and precisely control and generate the form of their intended geometry. Fu (2018) believes that parametric technology is efficient because it has the ability to model 3D visualizations that resemble real life attributes that can be manipulated to simulate a variety of simulations for the intended output of a project.

Fu (2018) also explains that the parametric modeling has its advantages in terms of efficiency. For example, with setting up a 3D geometric model, the shape of the model's geometry can be changed as soon as the parameters such as the dimensions or curvatures are modified. This indicates that designers can modify the entire shape of a model easily rather than having to redraw the model when using analogue design methods. Evidently, this ability significantly saves time for designers, specifically, as Fu (2018) suggests, during the schematic phase of design. Before parametric modeling, Fu (2018) explains that the scheme design was not an easy task for designers because the model was prone to frequent changes. Zhang et al., (2019) agrees with Fu (2018) that parametric modeling is efficient for testing designs. Zhang et al., (2019) believes that parametric technology has benefited new methods of design. Specifically, Zhang et al.,

(2019) performed a study on green energy conservation in the building industry. Zhang et al., (2019) expressed that utilizing parametric design as a performance simulation aided in providing feedback for modifying changes for the best optimization efficiency in building design. Evidently, Fu (2018) and Zhang et al., (2019) agree that parametric technology can be highly efficient in times of conserving workflow, time management, and for optimizing design solutions.

Although this section of the literature focuses on the efficiencies of parametric technology, the following section will further investigate the advantages and disadvantages of parametric technology and design.

2.8 Parametric Design: Advantages and Disadvantages

As explored through the literature review, parametric design offers the designer great liberty within their practice. Through this section of the literature review is an analysis of the advantages and disadvantages of utilizing parametric technology within landscape architecture. This leads to Cantrell and Mekies (2018)'s opinion on the benefits parametric design has on landscape architects and designers in general where they express that computational design and parametric design hold great potential and capability for designers. Similar to Erlendsson and Erk (2012)'s argument earlier, Cantrell and Mekies (2018) suggest that those designers who work parametrically may be thought of as someone who is flipping the traditional design process. This meaning, they are an editor of constraints first and an empirical designer once the constraints are designed (Cantrell & Mekies, 2018). Cantrell & Mekies (2018) refer to this idea as "optioneering" in which these types of designers are used to identify project constraints in the earlier stages, and they can do so through innovative computational design software. Marion et al., (2012) agrees with Cantrell and Mekies (2018) in that computed technologies services have accelerated the design process due to the proliferation of tools and IT solutions. The technology allows for designers to quickly produce prototype parts and virtual testing within a matter of hours (Marion et al., 2012).

Marion et al., (2012) suggest that although these digital design tools are invaluable for visualizing ideas and for quickly developing detailed designs, they are not sufficient without sound management practices. Marion et al., (2012) points out two issues with computed technology. The first issue is due to the technology that allows for a fast and completed looking design, this can create a false sense of security during the design process. Marion et al., (2012) explain that there is often a tendency for design teams to move onto the next stage of the design process before there is a fully comprehended understanding of the design. The second issue being the ease in which designs can be digitally drafted and prototyped can lead the final design product to become too fluid during the development process (Marion et al., 2012). This suggests that having a tool that can quickly iterate a design, can lead to constant revisions, which may lead to loss of time and added expenses to businesses (Marion et al., 2012). Evidently, the efficiency of parametric technology provides us can effectively mitigate the benefits of digital design in general.

Cantrell & Mekies (2018) examined an interview conducted by Paralabs, a computational design practice built on the notion that quality design emerges from a rigorous computational approach. Subsequently, an approach that utilizes more parameters to play with. Paralabs conducted this interview to investigate other successful practices who focus on computational design work from a design and business perspective (Cantrell & Mekies, 2018). The purpose was to capture a snapshot of how computed technology is being integrated and applied in practice. Cantrell and Mekies (2018) explain that because computational design comes in so many shapes and sizes, that to each individual practice, computed design was used for achieving efficiency, complexity or a unique aesthetic. Cantrell and Mekies (2018) express that the term “value” was used thoroughly during the interviews, to indicate many practices who used computational design use it with the intent to produce something that has lasting value and improves performances on the projects. Cantrell and Mekies (2018) agree with Marion et al., (2012) in that computational design has an impact on businesses in the sense of predictability and quickly changing the dynamics of the design and design profession.

Another disadvantage of parametric design that was identified during the Paralabs interview was that through a business operations lens, several of the practices struggled with balancing the supply of new possibilities demanded by clients (Cantrell and Mekies, 2018). Evidently, this leads back to Marion et al., (2012)’s argument where practices expressed that this led to them bypassing the traditional scope of work and engaging in parametric technology during the earlier stages of the design process (Cantrell and Mekies, 2018). As Marion et al., (2012) has expressed, this can lead to beautiful final look, however, skipping the essential earlier steps in the design process can lead to a failing design in the end. Cantrell and Mekies, (2018) in agreement with

Marion et al., (2012) also argue that this can create a liability issue with those producing the designs. In terms of economic stake, producers are making stylistic decisions rather than long term economic decisions to influence the design (Cantrell and Mekies, 2018).

Cantrell and Mekies (2018) suggest other methods of utilizing parametric technology to avoid these complications. For example, Cantrell and Mekies (2018) propose the idea of "productization", a method of design where a product is created to satisfy a variety of project types. This product can then be used to identify clients who are interested in what it offers. This further fosters a greater understanding of the benchmark that defines the shared value between profession and clients (Cantrell and Mekies, 2018). Cantrell and Mekies (2018) explain that those practices interviewed by Paralabs indicated they used the method of productization as their preferred method when working with parametric technology.

Although parametric technology shares both advantages and disadvantages, Cantrell and Mekies (2018) believe that its impact on the practice of landscape architecture has seen significant improvements in terms of digital workflows and stylistic impacts. Cantrell and Mekies (2018) and Marion et al., (2012) express that the technological challenges that the profession has faced are more so to do with fundamental discrepancies with project delivery and business models. Cantrell and Mekies (2018) and Walliss and Rahmann (2016) believe that landscape architecture is shifting away from utilizing digital tools as a way of representation and visualization, and instead moving towards critical reflection on design possibilities.

2.9 Conclusion

This literature review provides a well-rounded perspective on the emergence of digital design, specifically parametric design, in landscape architecture. Although it has been prevalent in architecture and engineering, it is still evolving in landscape architecture. Parametric design can be defined as an algorithmic system that utilizes mathematical equations that create functions with a variety of variables in a design. It is a type of technology that encourages users to attain their own liberty as a designer and to design beyond parameters. As research indicates, digital technology has been evolving within a short period of time and continues. It is often difficult to adopt the newest technology when it continues to innovate. Evidently, this has led to the field of landscape architecture to stick to traditional methods of computed aided drafting software's such as AutoCAD and SketchUp. It is suggested that this often leads to a gap between design school education and practice. Some research implies that digital technology, such as parametric design should be adopted within schooling to better prepare students for the working world. However, other research suggests it hinders their learning experience in among other areas.

Although parametric technology is a relatively new and emerging topic to landscape architecture, it continues to show its strengths and weaknesses. It is an innovative technology that provides practices and individuals significant benefits for designing beyond parameters. However, research indicates that if not managed properly, digital technology can create complications during the design process. Several literatures indicate that digital tools are beneficial to designers in that it offers more variety and unconventional methods. However, more research is needed to investigate methods of adopting parametric technology into the design process for producing efficient and effective designs. The purpose behind digital technology is to add lasting value and to improve performances on projects (Cantrell and Mekies, 2018). If this is not executed properly, design flaws can arise. In concluding remarks, more research on parametric design is needed. It is a tool of design that should not be hindered or seen as a replacement to traditional methods of design. Instead, parametric technology should be embraced for its innovation and adopted in the most efficient and effective ways possible.

3 Methods

3.1 Overview

Figure 3-1 provides an overview of the thesis methods. The methods have been used to evaluate the study's research goal and objectives. As Figure 3-1 suggests, the methods have been broken into three subsections.

The first method of analysis will be on three case studies from landscape architectural practices who utilize digital design technology for creating landscape designs. A comparative analysis has been conducted to attain an understanding on which techniques should be followed in order to utilize digital design technology efficiently during the design process.

The second method of analysis is a questionnaire, created by the thesis author. The questionnaire was sent to key informants in the landscape architectural profession to attain information on how digital design technology is being used in practice currently and whether it is being adopted efficiently into landscape designs.

The third method of analysis is to conduct a design experiment by creating a 3D model prototype using the computer software Rhinoceros 3D with the Grasshopper plug-in. The purpose of this research method was to test the parametric process against the ‘traditional analogue’ design process and to evaluate whether utilizing parametric design technology during a site analysis is efficient.

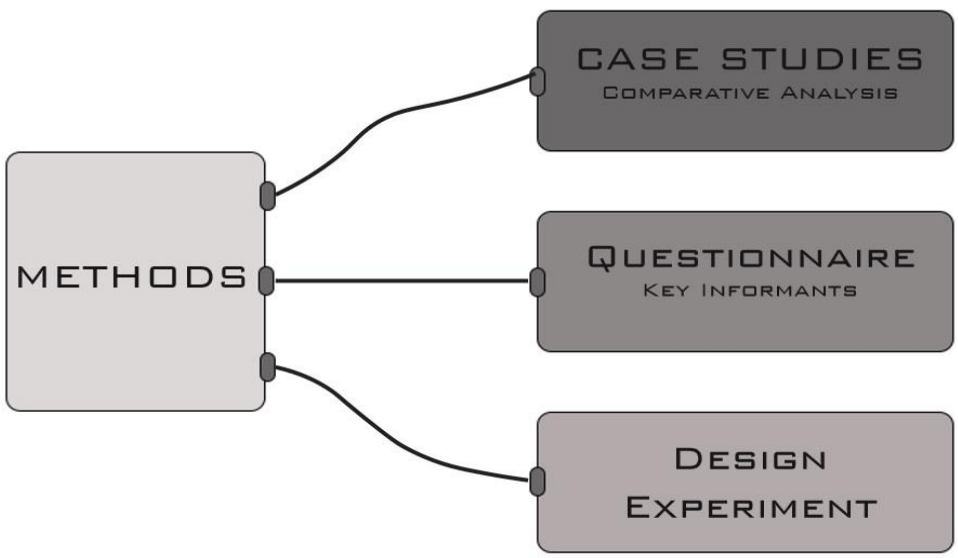

Figure 3-1 This illustration provides an overview of the methods section of this thesis. This flow chart is inspired by the design software Grasshopper (Source: Author).

3.2 Case Study Overview

Research in Landscape Architecture can involve a range of study types; however, case studies have been identified as being one of the more prominent research methods in this field (Van Den Brink et al., 2016). Specifically, this research included the study of multiple case studies by utilizing a systematic comparison method, known as a ‘comparative case study analysis’, to accumulate generalizable knowledge on the topic of parametric design and technology (Van Den Brink et a., 2016). The three chosen case studies were selected based on criteria. The following is a list of set criteria each case study must meet:

- Must be a landscape architectural, architectural, or urban design practice.
- Must be a globally recognized for design work and projects.
- Must have award winning designs.
- Must specialize or utilize digital design technology for creating design work.

Furthermore, this study will focus on three global landscape architecture practices that have utilized parametric digital technology for a design project and have successfully achieved an award-winning design project. Each case study will be broken down beginning with an overview of the practice and its parametric project, their design objections, and how they used parametric technology to achieve their objections.

3.3 Questionnaire Overview

The second method of data collection and analysis for this study is by using a descriptive social survey strategy such as a questionnaire, specifically, a closed questionnaire (Deming and Swaffield, 2011). The questionnaire was designed for key informants in the practice of landscape architecture who were asked to answer nine dichotomous ‘yes’ or ‘no’ questions and nine Likert scale questions (Deming and

Swaffield, 2011). The purpose of the questionnaire is to gather an understanding from landscape architecture professionals on how parametric design is being used in practice and whether it is being adopted efficiently and effectively into designs. The questionnaire was designed based on a set criterion; the following is a list of criteria created for the questionnaire:

- To attain a threshold of 20 to 25 responses.
- Must address the integration of efficiency of parametric design into the architecture and landscape architecture industries.
- Must address the 'gap' between education and practice in landscape architecture.
- Must address and evaluate parametric technology's efficiency and effectiveness regarding time management, work flow, and the design process in both the architecture and landscape architecture industries.
- Must evaluate the performance of parametric design technology in terms of promoting innovative design and complex forms.
- Must identify the prominent digital design software programs key informant are utilizing in the practice of landscape architecture.

The following is a list of criteria to follow for identifying the appropriate key informants for this study:

- Key informants must be a landscape architect, urban designer, or academic in the profession of landscape architecture.

- Key informants must have knowledge and experience with using digital design technology, specifically, parametric design.

3.4 Design Experimentation

The third method of data collection and analysis for this study is through conducting a design experiment by creating a prototype 3D model using the software Rhinoceros 3D with the Grasshopper plug-in. The purpose of this design experimentation is to test the parametric process against the traditional 'analogue' design process to evaluate the efficiency and effectiveness of utilizing parametric design technology during a site analysis.

4 Analysis & Results

4.1 Overview

In this chapter, is the analysis related to each method of research presented in Chapter 3. Following the analysis, the results from each method of research have been included.

4.2 Case Study: Fletcher Studio, Horseshoe Cove Competition Entry

Fletcher Studio is a landscape architecture and urban design collaborative practice located in San Francisco, California, United States of America (Fletcher Studio: About, 2018) The design practice was founded by its principle and owner, David

Fletcher, ASLA, RLA, in 2004 and has an extensive studio team of 12 members (Fletcher Studio: About, 2018). Fletcher Studio actively believes in leveraging technology to work faster and smarter, while also encompassing people, ideas and their culture to advance their designs and design process (Fletcher Studio: About, 2018). Ultimately, a key driver in their design process is to be collaborative, this enhances their way of thinking while also advocating for sustainable infrastructure and a meaningful experience for all (Fletcher Studio: About, 2018). The designer's at Fletcher Studio often will design parametrically using digital software's such as Rhinoceros 3D, Grasshopper and Rhinoscript to test complex forms, functions, and site layout (Amoroso, 2012). Furthermore, digital experimentation is a key driver at Fletcher Studio for providing a more thorough insight into spatial form and ecological performance (Amoroso, 2012).

4.2.1 Overview of Project

Located in the Marin headlands, California, Horseshoe Cove is a 32-acre park that has faced significant changes, spatially, programmatically, and ecologically over the last hundred years (Amoroso, 2012; Fletcher Studio: Projects, 2018). With the concern for a changing climate, this led to the call for design competition for the redevelopment and restoration of the site and beach's waterfront. A key component of the improvements for this site is to ensure the design accounts for being a responsive landscape, specifically for protecting the Fort Baker Cultural area from rising sea levels (Fletcher Studio: Projects, 2018). With this information, and in collaboration with Andrew Kudless, from Matsys Design, Fletcher Studio created a design concept that encompasses all the components of the vast landscape while also incorporating a dynamic and mixed-use site, see Figure 4-1.

Figure 4-1 Rendered Illustration of the Horseshoe Cove design by Fletcher Studio (Fletcher Studio: Projects, 2018).

4.2.2 Project Objectives

Fletcher Studio established some project objectives to ensure the competition requirements were met while also maintaining their own design values. The following objectives can be seen listed below:

- To create a site that is dynamic and mixed-use by constructing an interwoven landscape for both land and water (Amoroso, 2012).
- To account for environmental conditions such as sea level rise, groundwater and drainage, flora and fauna, wetland and bio-pools, and incorporating renewable energy technology; wind and solar power (Fletcher Studio: Projects, 2018).

- To incorporate a variety of activities ranging from active to passive recreation.
- To test various forms that link landscape and the sea, to create one cohesive site (Amoroso, 2012).

4.2.3 Parametric Technology

To achieve the set objectives, Fletcher Studio used advanced digital explorations to test a variety of forms and linkages between the landscape and the sea, see Figure 4-2, to determine the best design solutions for their concept (Amoroso, 2012). The computer software Rhinoceros 3D was used to create complex geometries and form-testing for their experimental design research (Amoroso, 2012). Using advanced digital technology like parametric design, allowed Fletcher Studio to increase the overall surface area at the 'folding' of the water's edge to the folded joint between land and water, furthermore, creating a larger central circulation route across the site (Amoroso, 2012; Fletcher Studio: Projects, 2018).

Figure 4-2 Illustration representing the various digital experimentations, such as programing, canopy, water, and ground plane, created for the Horseshoe Cove site (Fletcher Studio: Projects, 2018).

4.3 Case Study: Groundlab, Flowing Gardens

Groundlab is an international design practice, located in London, England, United Kingdom, focused in the fields of landscape architecture, urbanism, and architecture. Groundlab was founded by four directors: Eva Castro, Holger Kehne, Alfredo Ramirez and Eduardo Rico (Amoroso, 2012). Currently, Groundlab is led by the founding director in London, Jose Alfredo Ramirez; architect, landscape architect, and urbanist, and Clara

Oloriz; director, architect and PhD researcher (Groundlab: Team, 2020). Groundlab invests in taking a collaborative approach by bringing together a variety of expertise to employ insightful designs while also exploring a new mode of practice such as Landscape Urbanism (Groundlab: About, 2020). As an interdisciplinary practice, Groundlab believes in creating designs that can adapt themselves within a changing environment; therefore, incorporating changeability, flexibility, and resilience is essential for design (Amoroso, 2012). Furthermore, parametric technology is often used as a method of experimental modelling. Specifically, Groundlab uses parametric technology to create visionary landscapes and to test variable options for determining the best solution for urbanism in the future (Amoroso, 2012).

4.3.1 Overview of Project

The winning Flowing Gardens competition project, located in X'ian, China, was created in collaboration with Groundlab and Plasma Studio for the International Horticultural Expo in 2011 (Amoroso, 2012). Figure 4-3 displays the projects master plan; the site encompasses a balance of functionality between water, vegetation, circulation, architecture, and programming (Amoroso, 2012). Their proposal included designing for 37 hectares of landscape, this comprises of a 5000 square metre Exhibition Hall, a 4000 square metre Greenhouse and a 3500 square metre Gate Building (Groundlab: Our Works, 2020).

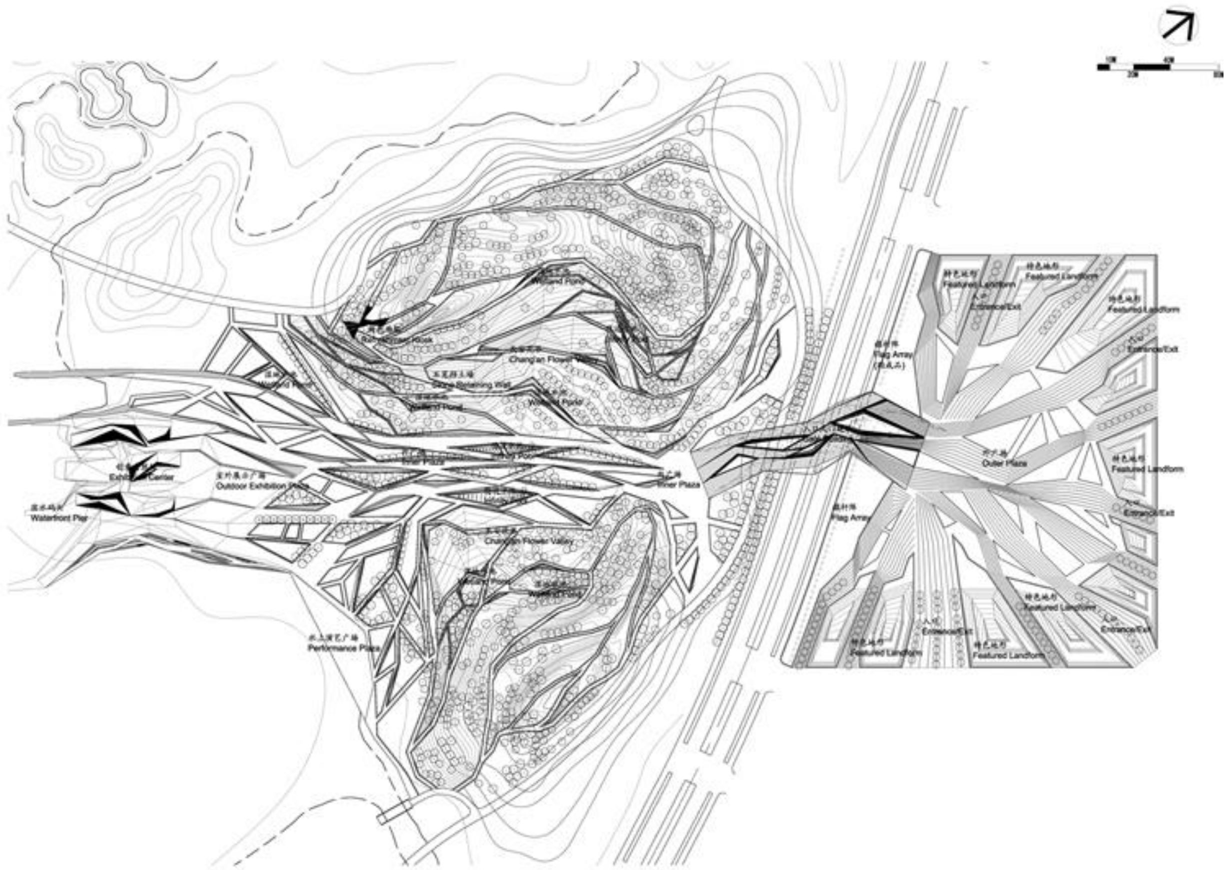

Figure 4-3 Digital Illustration of the Master Plan for Flowing Gardens, X'ian, China (Groundlab: Projects, 2019)

4.3.2 Project Objectives

The goal of their design was to give rise to a fluid and interconnected system while ensuring environmental and social sustainability (Bonafede, 2014). The following are a list of objections applied to the Flowing Gardens design:

- To create an interconnected hybrid system between architecture and landscape.
- To ensure environmental and social stewardship within the design.

- To create a design suited to be transformed into an urban park that offers a continuous landscape that extends from the city to the lake; establishing a relationship between constructed and natural elements (Bonafede, 2014).

4.3.3 Parametric Technology

The Flowing Gardens are a demonstration of how digital design experimentation is a beneficial tool for design (Bonafede, 2014). With having a short time to complete their work, parametric digital technologies were used to further develop their elastic and adaptive working process (Bonafede, 2014). Evidently, the end result exhibited a “cutting-edge” image for technological and environmental awareness (Bonafede, 2014). As shown in Figure 4-4, the design accounts for Groundlab and Plasma Studio’s objectives; a unified site was created, displaying a broken but interconnected mosaic between organic (landscape; flower beds, earthworks, ponds, etc.) and geometric (structure; buildings, bent laneways, roads, etc.) design (Bonafede, 2014).

Evidently, the unique formations displayed in Figure 4-5 are an example of ‘Voronoi diagraming’, a parametric design process (Şahin and Hatipoglu Şahin, 2017) where a given set of points (Voronoi points) are partitioning the space into organic sub-spaces, setting proximity relationships among the set of points (Pirlo and Impedovo, 2012). Applying this method allowed Groundlab, in collaboration with Plasma Studio, to assess public connections with the surrounding organic landscapes. Utilizing the ‘Voronoi’ method is useful for experimental design as it provides a quick and efficient method of understanding the relationships between objects within a given space.

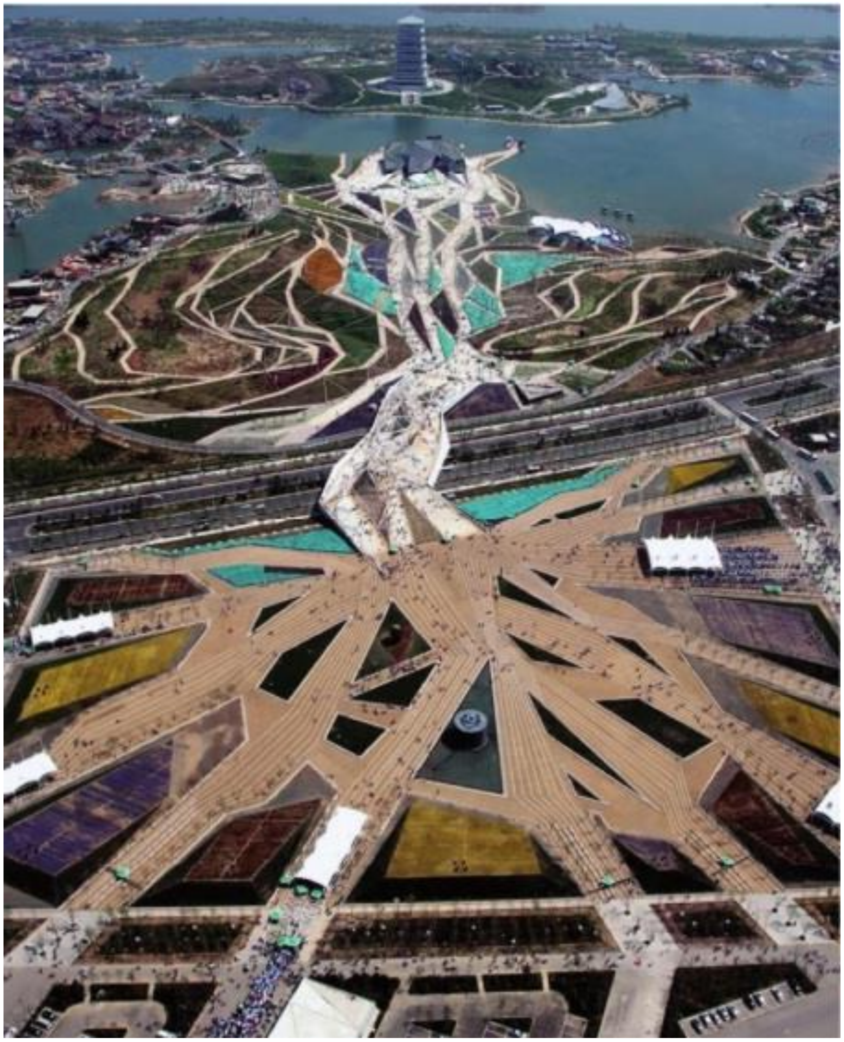

Figure 4-4 Flowing Garden completion, displaying an interconnection between organic landscape and structural geometry (Bonafede, 2014).

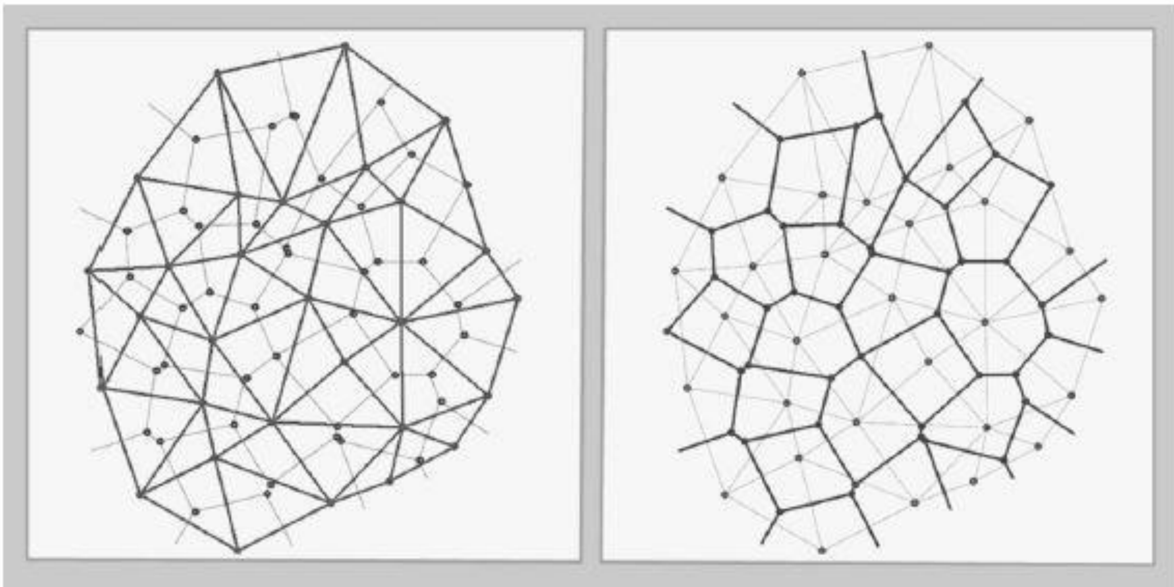

Figure 4-5 Examples of Delaunay triangulation and Voronoi-based zoning methods (Şahin and Hatipoglu Şahin, 2017). Voronoi zoning offers the possibility to easily adapt the zoning to the specific characteristics. Voronoi diagraming is used as a means of naturally partitioning a space into zones (Pirlo and Impedovo, 2012)

4.4 Case Study: Stoss, Erie Plaza

Stoss is an urban and landscape revitalization practice that focuses on creating resilient spaces that encompass vitality, equality and community within the public realm (Stoss: About, 2019). Stoss is a Boston based design firm that was founded in 2001 by the practice’s director, Chris Reed, a recognized international leader in voicing the transformation of landscapes and cities, while also working as a researcher, designer, and professor at the Harvard University Graduate School of Design (Stoss: About, 2019). Stoss values the concept of landscape urbanism; creating landscapes that connect people to their environment, to work in collaboration, effectively, and efficiently, and to achieve design solutions that identify and solve problems while also encompassing community support (Stoss: About, 2019). Stoss emphasizes incorporating time and phasing into their design process, to aid in this, the practice often relies on digital technologies such as Rhinoceros 3D, Flamingo, Illustrator, Photoshop, and AutoCAD, as well as exploring parametric scripting processes (Amoroso, 2012).

4.4.1 Overview of Project

Erie Plaza is a public space located along the Milwaukee Riverwalk, a 4.8km long pedestrian strip connecting downtown Milwaukee to the Third Ward, Beerline districts, and the lakefront in Milwaukee, Wisconsin, United States of America (Amoroso, 2012). Stoss ensured to create a space that can be adaptable, flexible, and sustainable, regardless of environmental conditions (Amoroso, 2012). To understand this, Stoss invested in an experimental digital design process using the software programs Rhinoceros 3D, Grasshopper, Flamingo, AutoCAD, Illustrator and Photoshop (Amoroso, 2012). By utilizing advanced digital software’s, this allowed Stoss to experiment with making a space that could be performative and flexible, see Figure 4-6 for an overview of the site.

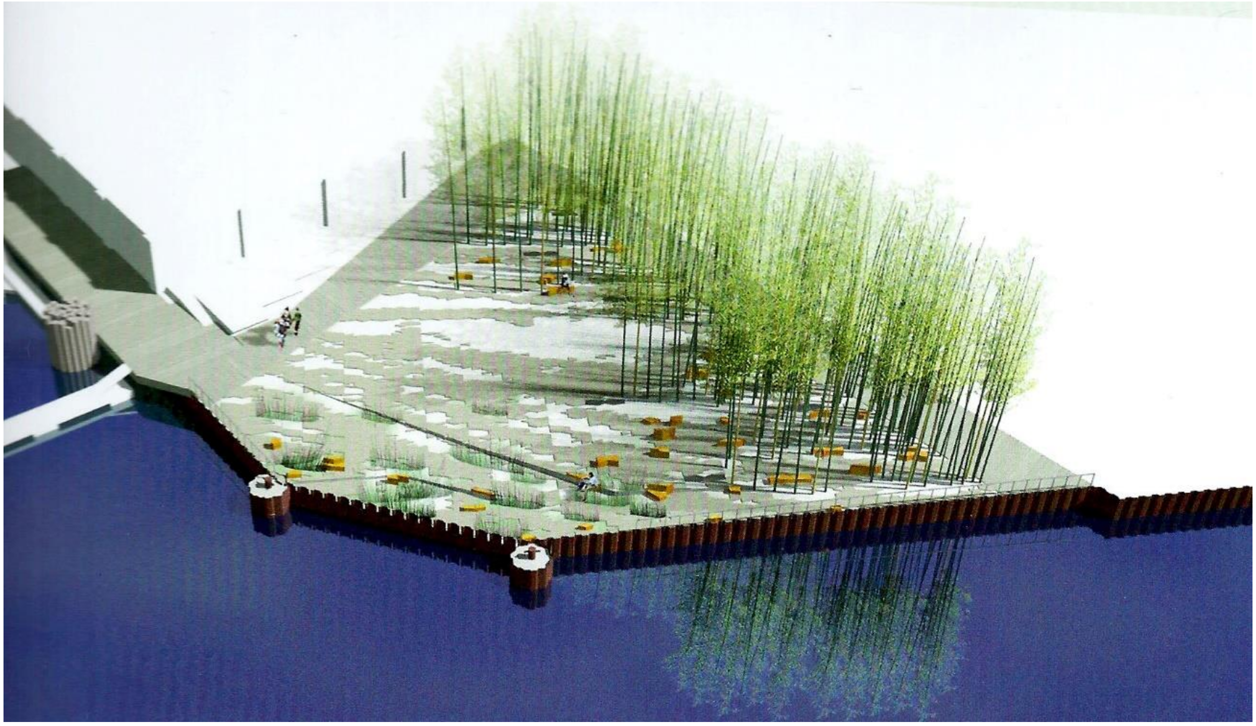

Figure 4-6 Overview of Erie Plaza site design (Amoroso, 2012)

4.4.2 Project Objectives

The goals of the Erie Plaza site design were to create an experimental yet harmonious space that encompasses environmental conditions and human movement throughout the site (Amoroso, 2012). The following are a list of objectives given to the Erie Plaza design:

- To create a flexible and adaptive site design that is interconnected with the rest of the City of Milwaukee and that encourages cultural and environmental activities and uses (Amoroso, 2012).
- To account for the changes and conditions of environmental cycles, specifically, storm water run-off.

- To utilize performative-based guidelines for designing the site.

4.4.3 Parametric Technology

The software's Rhinoceros 3D and Grasshopper were used as the primary digital technologies for designing Erie Plaza. Utilizing this technology helped Stoss achieve a performative design. Stoss was able to produce a flexible design through creating a series of mixed components/events, evidently allowing for the team to test dynamic surface conditions and to integrate environmental conditions (Amoroso, 2012). Figure 4-7 provides a visualization of potential events, both social and environmental considerations, that could emerge at Erie Plaza. Figure 4-7 displays 4 experimental scenarios, the first of the overall site, the second displaying a concert or event space, the third of human interactive gathering spaces throughout the site, the last displaying environmental changes that account for stormwater run-off (Amoroso, 2012).

Figure 4-8 provides an overview of pathfinding of human interactions of the site. Stoss experimented with an interlocking paving pattern, as shown in Figure 4-8, that outlined a clever medium through which a collection of various scenarios/site amenities were placed (Amoroso, 2012). Utilizing a pathfinding method for designing a space aids in producing the most efficient outcome possible. Parametric technology such as Rhinoceros 3D and Grasshopper allows the performance-based method of the pathfinding to be employed smoothly for designers while also identifying various scenarios for the overall design.

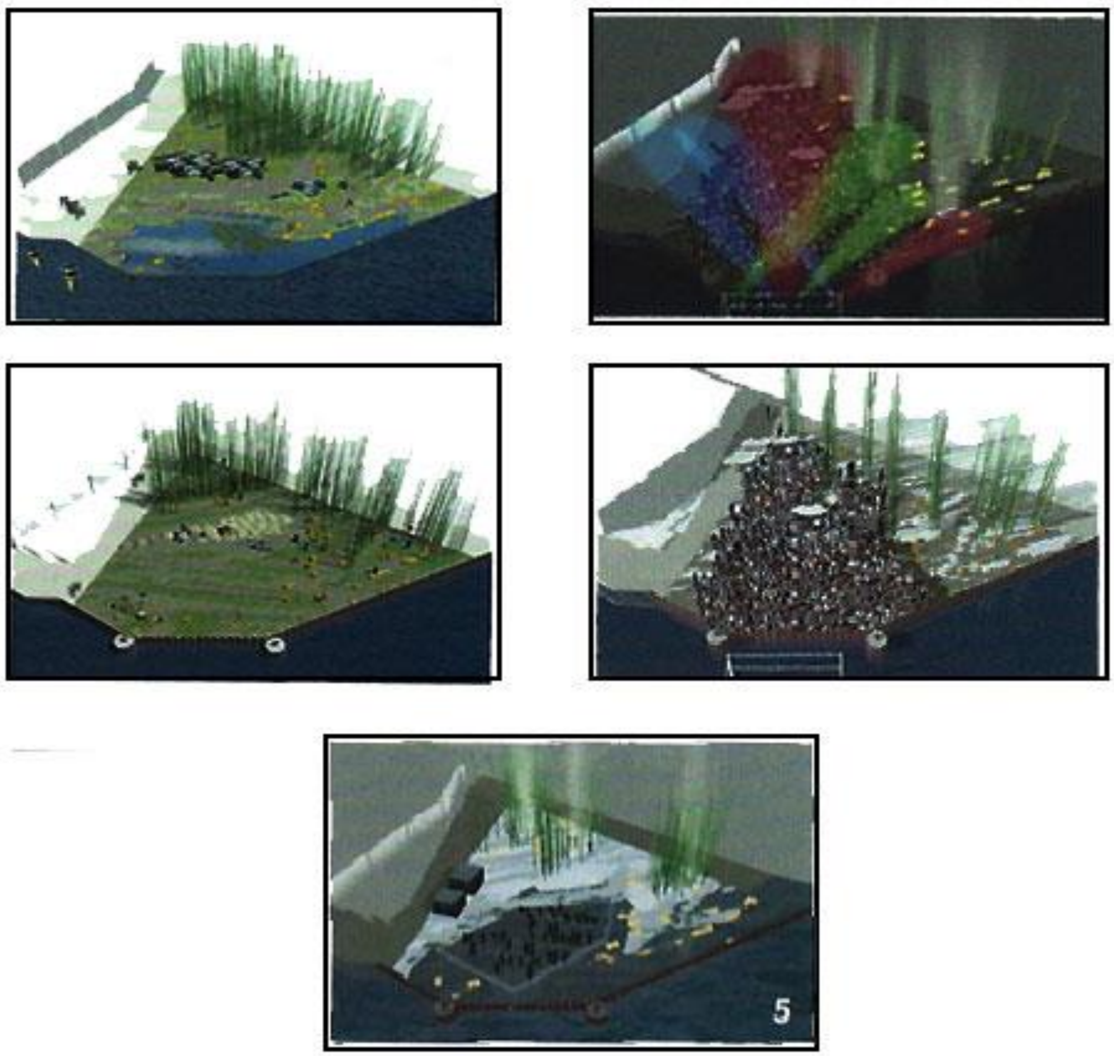

Figure 4-7 Scenario of event space and changes in the landscape (Amoroso, 2012)

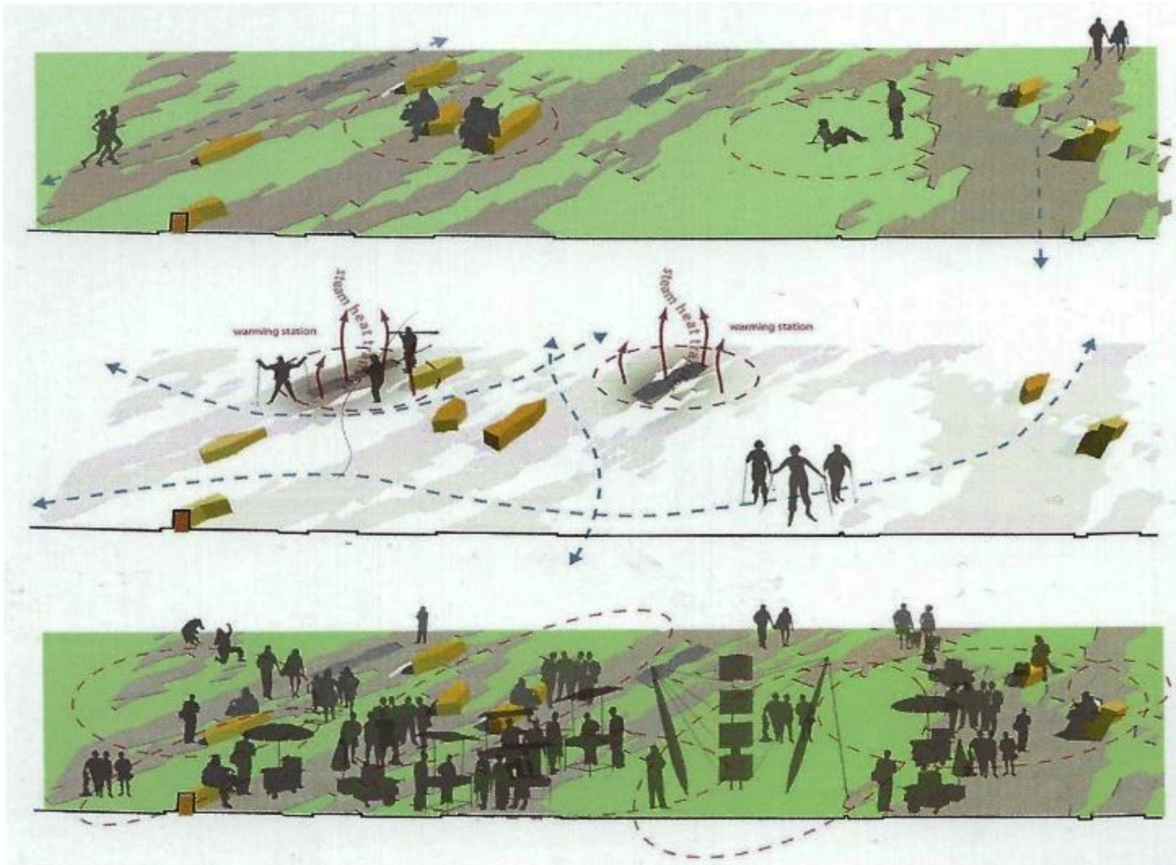

Figure 4-8 Conceptual development of interactions throughout Erie Plaza site (Amoroso, 2012).

4.5 Systematic Case Study Comparison

This section will focus on a systematic comparison of the chosen three case studies. A 'cross-case comparison' method will be used to analyze and gather information from each case study, see Figure 4-9. Van den Brink et al., (2016) explain that this method of analysis is appropriate for a research design that seeks to answer its questions by comparing different cases. The cross-case analysis allows for the mobilization and accumulation of knowledge for each individual case study to then compare and contrast the cases to produce new knowledge (Van den Brink et al., 2016).

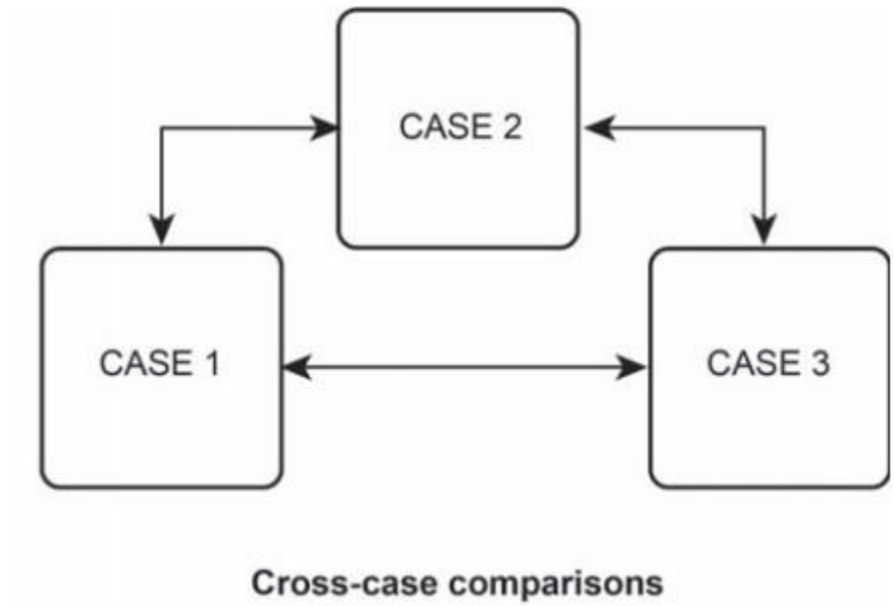

Figure 4-9 This figure displays a diagram of the 'Cross-case comparison' analysis approach for data collection with the use of multiple case studies (Van den Brink et al., 2016).

Utilizing ‘multiple cases’ is more compelling than using single cases, this allows for a more comprehensive and robust comparison while also serving to explore a different element of the topic (Van den Brink et al., 2016). Furthermore, this thesis seeks to identify a critical strategy on how to efficiently and effectively adopt the parametric process into landscape architecture. Therefore, assessing the processes in each case study and how they utilized parametric technology will be used to identify a potential approach.

4.5.1 Performative/Experimental Design

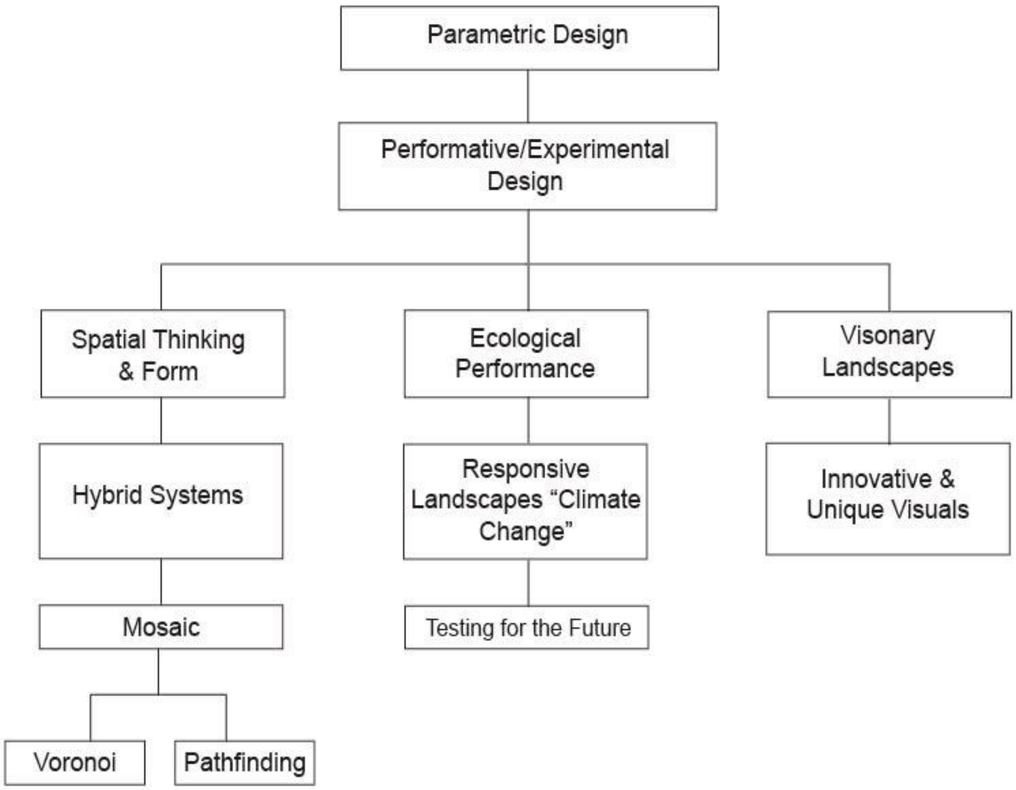

Figure 4-10 Comparative Analysis Diagram of the three case studies. This diagram highlights similarities and key points between case studies to further understand the use of parametric technology amongst professional landscape architectural practices (Source: Author).

Figure 4-10 provides an overview of the comparative analysis of the three case studies. The primary theme that arose from each case study analysis is that parametric design can enhance the performative/experimental design approach. Performative design is often used with digital design technology to test the way the built environment is already designed (source). Each of the three case studies utilized this method of performative/experimental design to ensure their projects can produce the most optimal design result for their specific site. By utilizing this approach, it has the ability to further break down into themes, see Figure 4-10, which also aid in producing favourable design results. Figure 4-10 suggest that designers are able to explore spatial thinking and form more thoroughly, ecological performance is enhanced, and visionary landscapes can be produced by utilizing this approach.

4.5.2 Spatial Thinking & Form

As the comparative analysis recommends, Figure 4-10 explains that performative/experimental design can invoke innovative spatial thinking and form within landscape designs. Furthermore, this strategy allows designers to attain a thorough understanding of the relationships between shapes, form, objects, and other amenities on their site. All three case studies suggest that by utilizing the performative/experimental design approach, designers also are able to create an interconnected design that promote hybrid systems.

For example, Groundlab utilize the voronoi patterning mechanism to attain an understanding between objects within their designated site; an innovative method of spatial thinking. Stoss utilize a pathfinding mechanism to understand the circulation of their site and to identify the most efficient points of entry and exit. Stoss also utilized the pathfinding mechanism to test their site conditions during different events, such as passive or active recreational activities. Fletcher Studio was able to test a variety of forms and linkages from utilizing the performative design approach. With this, spatially, Fletcher Studio was able to create a design that incorporated complex geometries that link both hardscape and softscape to the overall site.

Furthermore, this comparative analysis suggests that adopting parametric technology for conducting a performative/experimental design approach encourages the opportunity for designers to enhance their spatial thinking and understanding of form for landscape designs.

4.5.3 Ecological Performance

Utilizing parametric technology through the performative design approach enhances the ecological performance of landscape designs. With climate change being a prominent topic globally, designers must be aware of the current and future conditions of their sites. Furthermore, parametric technology is a good method of design to create responsive landscapes.

For example, with Fletcher Studio's design for Horseshoe Cove, the practice wanted to create a design that is adaptive and resilient to change. Therefore, their strategy was to follow a performative design approach by utilizing parametric technology to test scenarios for their site. By doing this, Fletcher Studio was able to test and evaluate their site for climate change, specifically sea level rise.

Stoss's project at Erie Plaza is an example of where parametric technology allows for the ability to test for environmental conditions. Erie Plaza is location on the river's edge of the Milwaukee Riverwalk, therefore, Stoss wanted to test their site, specifically, testing for stormwater run-off and for creating a dynamic surface for the site's pathways.

Similarly, Groundlab believes in utilizing parametric technology to produce adaptive designs that can be resilient presently and in the future. Furthermore, this comparative analysis suggests that parametric design can efficiently utilize the performative design approach for testing the ecological performance of landscape designs. With this ability, designers are able to create designs that are efficient for the current environmental conditions while also preparing for future conditions.

4.5.4 Visionary Landscapes

During the comparative analysis, each case study suggests that by utilizing parametric technology for a performative/experimental design approach invokes visionary landscapes. To expand off this, visionary landscapes appeal to an inventive or imaginative sense of place that is constructive in a way that holds a strong vision for the future. For example, Groundlab expresses that parametric technology can create unconventional and innovative designs, unlike conventional design methods. This is due to the technologies versatility and ability to produce designs quickly and efficiently.

Fletcher Studio suggests that parametric technology has the ability to make changes to designs flexibly and effortlessly while incorporating an overall unique aesthetic. Therefore, this comparative analysis suggests that designers have the opportunity to create visionary landscape by adopting the parametric process. By doing so, they can produce unique and contemporary designs while holding a strong vision for the future of their design.

4.6 Questionnaire

The questionnaire research method was conducted to attain a greater understanding of how parametric technology is being utilized in landscape architecture currently and how it impacts the design process, specifically, for landscape designs.

The following questionnaire (see Appendix A) was sent out to 25 key informants who are professionals (academics, principles, or senior staff) within the practice of landscape architecture. Out of the 25 key informants, 16 responded to the dichotomous ‘yes’ or ‘no’ questions and 15 responded to the ‘Likert Scale’ questions. Overall, 16 key informants responded to the questionnaire. Furthermore, the following section below will assess the questionnaire by each category of questions.

4.6.1 Dichotomous ‘Yes’ or ‘No’ Questions

This section of the questionnaire (see Appendix A) contains 9 dichotomous ‘yes’ or ‘no’ questions. Each of the 9 questions focus on the key informant’s backgrounds pertaining to parametric design and their opinion on utilizing parametric technology for architectural and landscape architectural designs. Figure 4-11 displays the overall percentages of each dichotomous question. Each question was answered on a ‘yes’ or ‘no’ basis. When analyzing the data, if a key informant answered ‘yes’, a number 1 was indicated. If a key informant answered ‘no’, a number 0 was indicated. Once the data was inputted, each question was calculated based on a percentage.

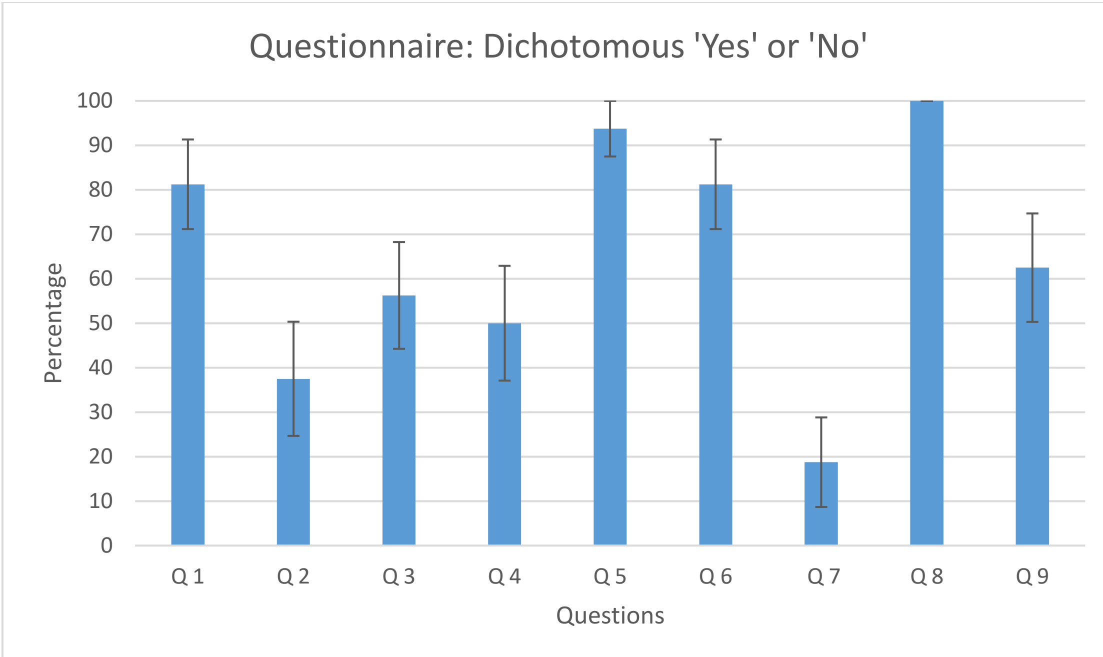

Figure 4-11 This table illustrates the percentage of each dichotomous 'yes' or 'no' questions in the questionnaire research method (Source: Author).

While reviewing the data, it is apparent that there is a trend. As questions 1,5,6, and 8 indicate, 80 to 100 percent of the key informants answered yes. Specifically, questions 5 and 8 with the highest percentages answering yes. Question 5 asked "*do you believe there is a gap between education and the working industry in terms of training for parametric technology";* this indicates that with the sample group of 16 key informants, about 90 to 100 percent of them believe there is a gap in education and in practice regarding training in parametric technology. Evidently, this supports prior research arguments that were assessed in Chapter 2's Literature Review, specifically with Schnabel (2007); Fischer and Herr (2002); Cantrell and Michaels (2010); and Love (2009) in that they have indicated there is a gap between education and practice regarding advanced digital design technology. Question 8 answered with 100 percent certainty.

Regarding questions 3, 4, and 9, the percentages indicate there is some variation between the key informants. Question 3 asks "*is parametric design being integrated/implemented efficiently into your design process*", about 55 percent of the key informant believe 'yes', the other 45 percent believe 'no'. With question 4, there is a 50/50 indication between the key informants. This reveals that professionals in practice have a comparable opinion on whether parametric design has changed their firms' approach. Question 9 indicates just above 60 percent of the key informants indicated 'yes' to the question. With this information, about 60 percent of key informants believe in promoting or utilizing parametric technology in the studio environment and for school-based projects.

Questions 2 and 7 has indicated significant variation between the rest of the questions, specifically, these two questions had a higher 'no' response rate. Question 2 asked, "*Do you think parametric design is being integrated/implemented efficiently into landscape architecture*"? About 35 percent of the key informants indicated 'yes' to the question, the rest, about 75 percent, indicated 'no'. This information supports Ervin (2001) and Pihlak (2004)'s argument in that they believe parametric technology is present, specifically in architecture, however, regarding landscape architecture, parametric technology is not being integrated efficiently and lacks progression.

Question 7 had the most variation regarding questions being answered ‘no’. Specifically, question 7 asked “*does the parametric process hinder the traditional design process*”? About just under 20 percent of the key informants answered ‘yes’, the rest, about 80 percent, answered ‘no’. Furthermore, this analysis supports Cantrell and Michaels (2010); Pihlak (2004); and Ervin (2001)’s argument in that traditional analogue design plays a vital role in the application of digital design tools rather than it hindering it.

4.6.2 ‘Likert Scale’ Questions

This section of the questionnaire (see Appendix A) contains nine (9) ‘Likert Scale’ questions. This section of the questionnaire focuses on questions pertaining to performance quality, time management, workflow, and usability of parametric technology. Each question is formulated with a rating scale; ratings from 1 to 5. The ratings are applied as shown; 1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = excellent. Although 16 key informants responded to the dichotomous ‘yes’ or ‘no’ questions, only 15 key informants responded to the ‘Likert Scale’ questions. Furthermore, the key informants were asked to rate their opinion for each of the 9 ‘Likert Scale’ questions. The following below provides an overview of the percentage data collected for each question, see Figure 4-12.

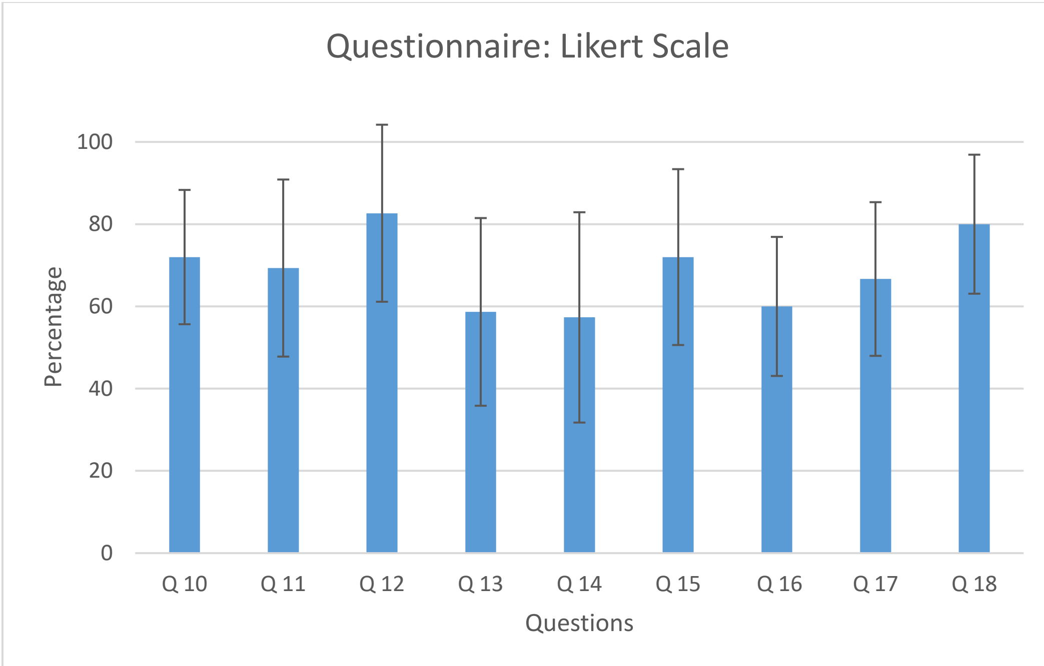

Figure 4-12 This is a graph that illustrates the response percentages of the 9 'Likert Scale' questions within the questionnaire research method (Source: Author).

While analyzing the data, the data was interpreted as a percentage scale. The ‘Likert Scale’ ratings from 1 to 5 correspond with a percentage scale. For example, 1 = 20 percent, 2 = 40 percent, 3 = 60 percent, 4 = 80 percent, and 5 = 100. If the key informant did not respond to a question it is indicated as 0 percent. Furthermore, the following below pinpoint the analysis and results given within the questionnaires ‘Likert Scale’.

Beginning with questions 10, 11, 15, and 17. The percentage between these four questions range from about 65 to 77 percent, specifically, question 10 (72 percent), 11 (69 percent), 15 (72 percent) and 17 (67 percent). This percentage range indicates that the average answer among the key informants for those questions was about ‘Fair’ to ‘Good’.

Questions 10 and 11 focus on rating the performance quality of parametric technology in the design process and in landscape designs. Again, the average for these two questions is about 70.5 percent, this indicates that their opinions on these questions ranged between ‘Fair’ and ‘Good’ regarding performance quality. Question 10 correlates interestingly with Schnabel (2007) and Zhang et al., (2019) in that they argue that the performance quality parametric design provides to the design process is effective, specifically, during the earlier stages of the design process.

However, question 10 in the questionnaire does not specifically indicate which stage the key informants believe parametric design should be used during the design process, rather, it suggests whether it is beneficial or not during the design process. Interestingly, the results from question 10 contradicts Monedero (2000)’s argument in which he believes utilizing parametric design, specifically, in the beginning of the design process is not effective because it advances designs too quickly, leaving the opportunity for errors.

Regarding question 11, key informants were asked to rate the performance quality parametric design has on landscape designs. The questionnaire results suggest the average between the 15 key informants was about 69 percent, indicating a ‘Fair’ to ‘Good’ response regarding performance quality of landscape designs. This result supports Monedero (2000)’s argument in which he believes advanced digital design technology produces aesthetically advanced designs. However, this result contradicts Pihlack (2004) and Ervin (2001)'s arguments in which they believe utilizing certain advanced design technology actually lack visual qualities. Specifically, Pihlack (2004) expresses that environmental design arts have stalled in landscape architecture due to the non-expressive visual quality from the prominently used computer design application software's such as AutoCAD and ArcGIS. To expand off this, Ervin (2001) argues that digital landscape models can lack 'realistic depictions' of landscapes, specifically, when representing basic elements such as terrain, vegetation, and water. However, Pihlack (2004) and Ervin (2001) are not opposed to digital modeling for landscape designs, rather they believe digital techniques are in their infancy and further research on specific application strategies should be assessed to improve digital visualizations.

Analyzing questions 13, 14, and 16, the responses to these three questions reveal the lowest rated responses with the average percent ranging from 57 percent to 60 percent. Question 13 had a response percentage of 59, question 14 had a response percentage of 57, and question 16 had a response percentage of 60 percent. Furthermore, this indicates that the majority of opinions on these three questions was a response indicating 'Fair'. Interestingly, these three questions focused on the navigation, user friendliness, and time management of parametric technology. Between the three questions, question 14, which focused on user friendliness of parametric technology, had the lowest percentage of 57 percent. Evidently, this result reasonably supports Monedero (2000)'s argument in that he suggests advanced digital design technology is not user friendly.

Questions 12 and 18 had the highest rated responses with percentages averaging between the two at 81.5 percent; question 12's average at 83 percent and question 18's average at 80 percent. These two questions are not comparable questions. Furthermore, they will be analyzed separately.

Question 12 focuses on rating the performance quality of parametric technology for architectural designs. The average response amongst the key informants was just above 'Good'. This result supports the research addressed in Chapter 2's Literature Review subsection, 2.4 Parametric Design in Architecture, where parametric design is discussed in detail on its quality for creating innovative architectural forms and designs. The results also support Çalışkan (2017) and Kara (2010)'s argument in that parametric design technology is prominently and effectively used in the architectural industry.

Question 18 focuses on rating parametric design technology for producing complex forms and designs quickly. The average response for question 18 was 'Good'. Furthermore, this supports Çalışkan (2017)'s argument where parametric technology is favorably used to produce dynamic forms and patterns while also designing with control.

In concluding remarks, it is apart that the questionnaire provides an interesting analysis and results from the perspective of landscape architectural professionals in practice. Evidently, this information can be used for further research on the topic of parametric design. Further discussion on these results will be evaluated in Chapter 5's Discussion and Chapter 6's Conclusion sections of this thesis.

4.7 Design Experimentation: Prototype 3D Model

The 'Design Experiment' was conducted to test the parametric process against the 'traditional analogue' design process and to evaluate the efficiency and versatility of utilizing parametric design technology for landscape designs.

The approach for conducting this design experiment was influenced by the results attained in Chapter 4, sub section 4.4 Systematic Case Study Comparison, see Figure 4-10, where information from the three case studies was analyzed to formulate a criterion to follow for creating the prototype 3D model. Evidently, the criteria created will be based on the design methods each case study used during their digital design process. The following is a list of steps that will be followed for conducting the prototype 3D model:

- This model will be created and tested by a parametric 'novice' designer
- A performative/experimental approach will be used as the primary design approach.
- A 'voronoi' and 'pathfinding' method will be used for conducting a site analysis for understanding spatiality and pedestrian circulation.
- The model will be created utilizing the digital design software Rhinoceros 3D computer application with the Grasshopper plug-in.

4.7.1 Definitions of Design Approaches

The following is a list of definitions of the primary and secondary design approaches used within the prototype model design experiment.

- *Performative Design*: utilizing digital design technology to test the environment.
- *Voronoi Diagram*: a diagraming method of naturally partitioning a space into zones to understand a sites spatial relationship amongst objects.
- *Pathfinding*: a method of identifying the shortest and most efficient route throughout a site.

4.7.2 Site Location

To test the parametric process, a site location was selected for the design experiment. Based on feasibility and accessibility for visiting the site regularly, the chosen space is located at 'Branion Plaza' on the University of Guelph campus. To simplify the space, a rectangular boundary was placed within the site; the design experiment was only conducted within this boundary, see Figure 4-13.

Figure 4-13 Branion Plaza, the design experiment site location, University of Guelph. The design experiment was conducted within the rectangular boundary (Source: Author).

4.7.3 'Traditional Analogue' Design Approach

To test the parametric process against the 'traditional analogue' design process, a schematic site analysis conducted through quick sketches. An AutoCAD file of the site was used as the base for the site analysis. The primary goal of this analysis was to identify critical gathering points and to assess the pedestrian circulation throughout the site.

Figure 4-14 displays a schematic sketch of the various gathering points located on the site using a voronoi diagram. This strategy of identifying the gathering points is to understand spatially the relationships between objects within the site. Evidently, this only provides a conceptual understanding of Branion Plaza spatially.

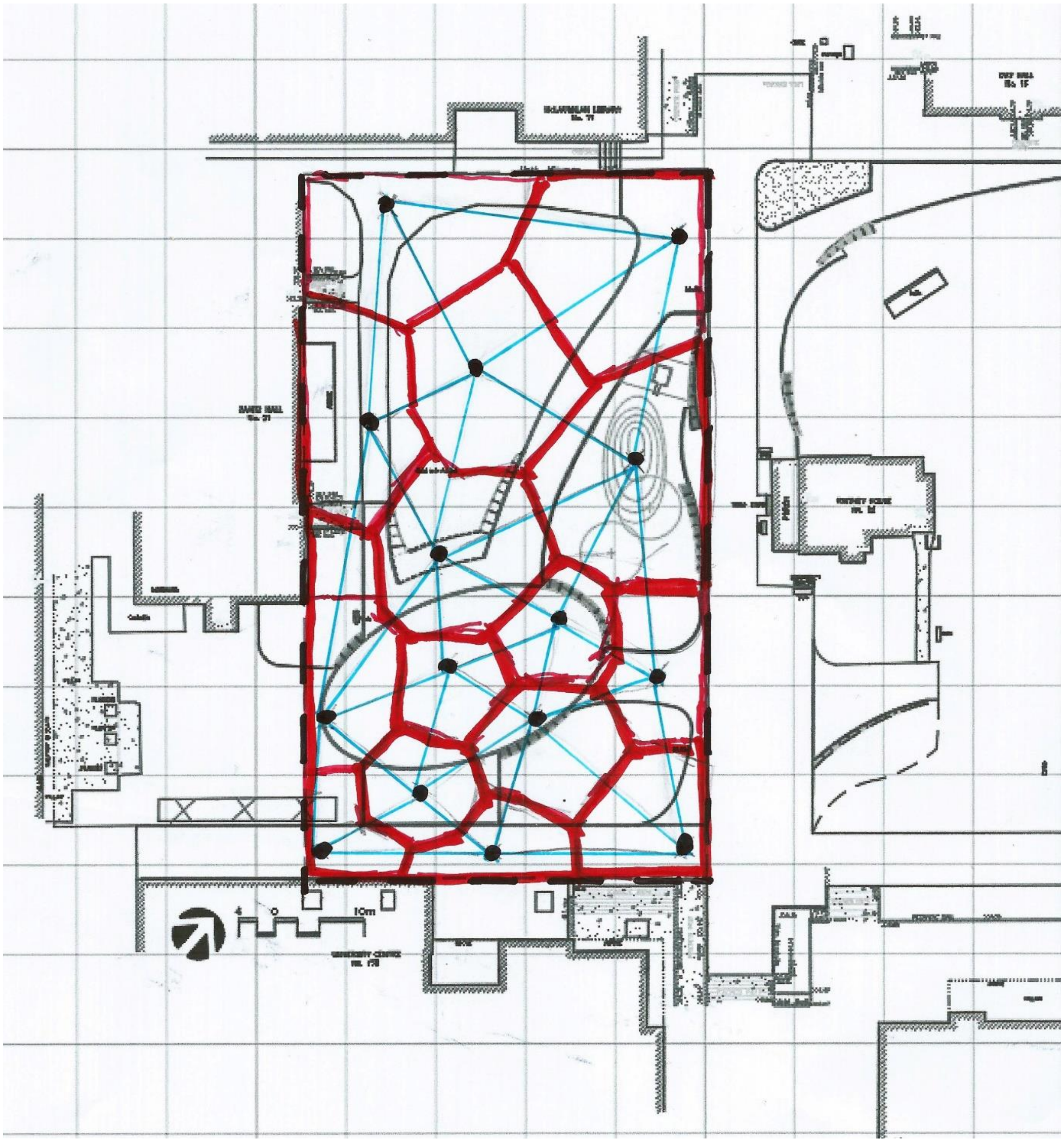

Figure 4-14 This is an illustration of the identified gathering points throughout the site, a method of analysis to understand the site objects spatially (Source: Author).

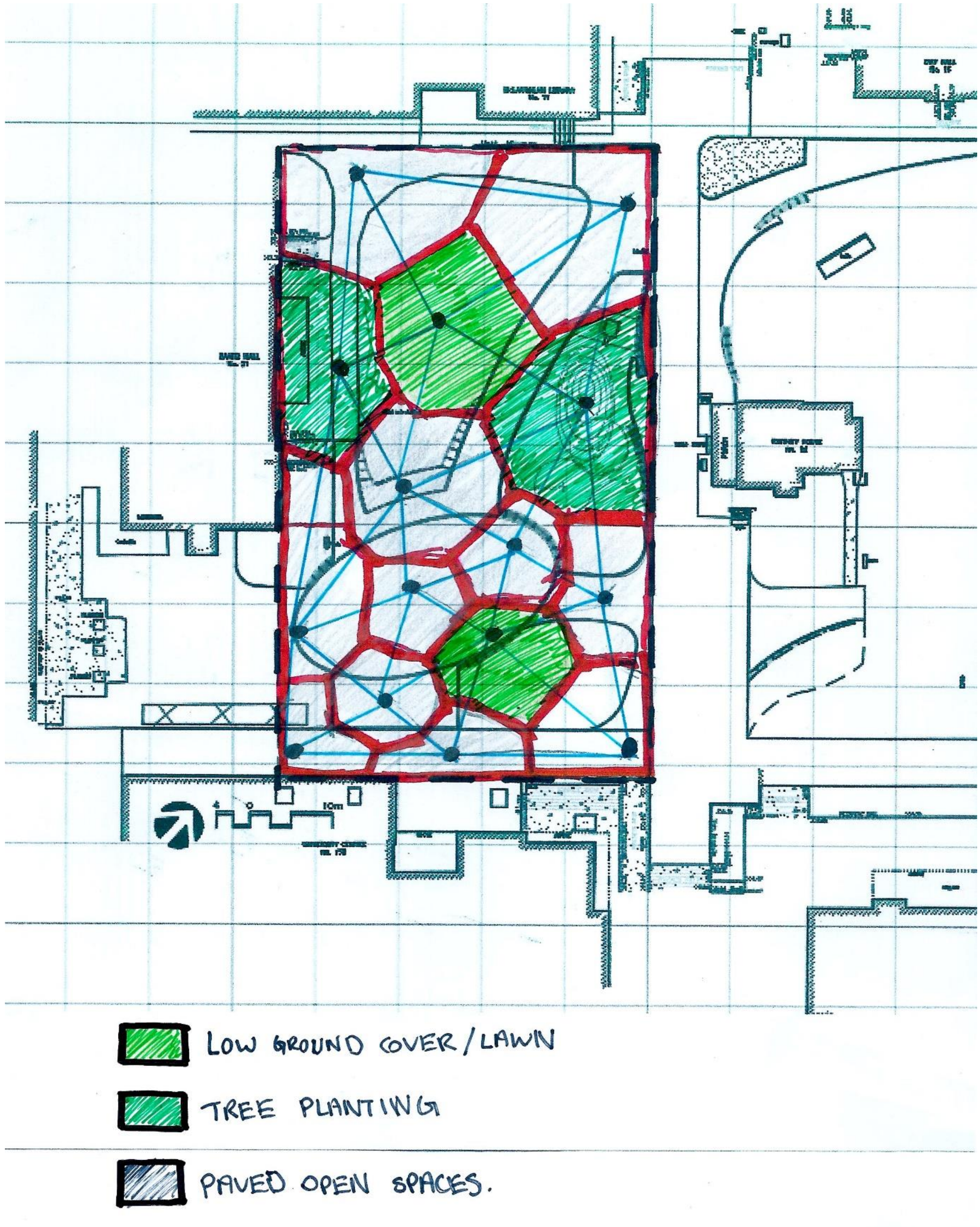

Figure 4-15 This is an illustration of the sketched voronoi diagram mapping the current soft and hardscape throughout the site (Source: Author).

To expand off this, Figure 4-15 identifies approximately the current areas of hard and softscape throughout the site using the voronoi diagram method. This is beneficial for designers to understand the spatial relationships between a site's hard and softscape, and therefore, can strategically plan their site's design. Specifically, the voronoi diagram method used in grasshopper can produce both natural/organic forms and regular geometries. The generation ability of organic/natural forms is capable due to the grasshopper's component ability for such geometries. The voronoi method is also used as a solvent tool for clarifying problematic issues, for example, regarding spatial relationships amongst objects or features on a site.

Figure 4-16 and Figure 4-17 display different options of pedestrian circulation throughout 'Branion Plaza'. Evidently, there are a variety of different routes pedestrians can follow throughout this site. However, the purpose of sketching the possible circulation routes is to identify the shortest and most efficient routes throughout this site.

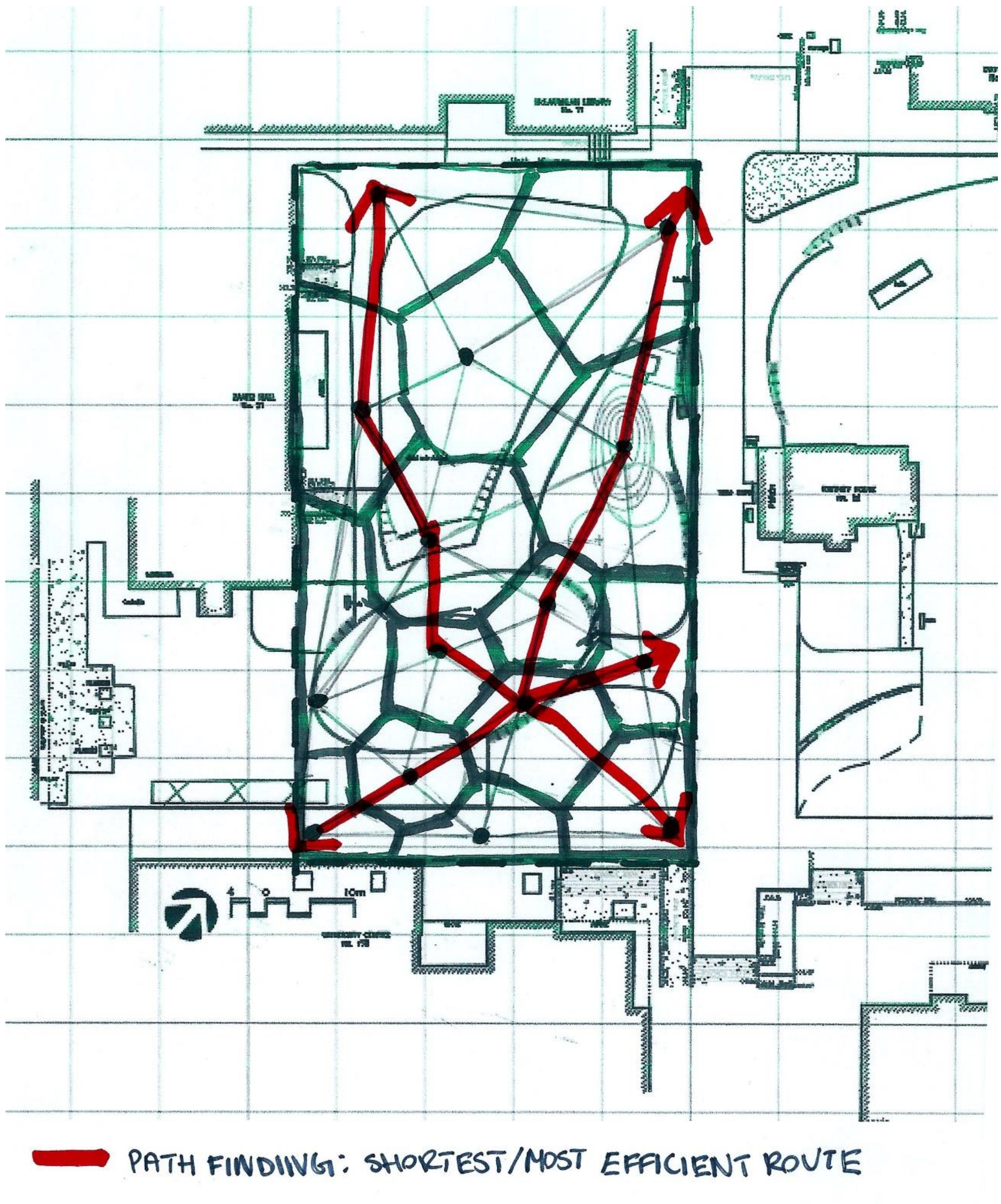

Figure 4-16 This is a sketched illustration of using the voronoi diagraming method to assess pedestrian circulation, specifically, identifying the shortest most efficient routes throughout the site (Source: Author).

Figure 4-17 This is a sketched illustration of the voronoi diagraming method used for identifying to most efficient/shortest routes throughout the site. By hand drawing these routes, this only gives an estimated understanding of what routes make the most sense and what are the most efficient for pedestrians to follow (Source: Author).

Specifically, Figure 4-16 provides an analysis of the possible shortest and most efficient pedestrian routes entering and exiting the site. Figure 4-17 provides an analysis of the possible shortest route within the site. These only provide conceptual analyses of pedestrian circulation on ‘Branion Plaza’. Evidently, the sketched analyses do not provide a concrete result of which routes are the shortest and most efficient for pedestrian circulation, rather it provides hypothetical situations. However, a method to determine these routes can be conducted by using a performative/experimental design approach with parametric technology. Furthermore, the next step of this design experiment will be to test the parametric process. To do this, a site analysis of ‘Branion Plaza’ will be conducted through the computer application software Rhinoceros 3D with the Grasshopper plug-in.

4.7.4 Parametric Design Approach

To begin the digital design experiment, the first step was to identify key attractor points to represent specific gathering points throughout the site. This is important for understanding the spatial relationships between where people are gathering on site in proximity with each other and with surrounding objects. Furthermore, with this information, a voronoi diagram was generated to display each individual gathering point. Figure 4-18 exhibits the voronoi pattern, the surrounding boundary at each gathering point represents a sub-space or ‘cell’. The sub-spaces partition the site into individual pods and can be used to determine the minimal distance needed to reach a certain feature or area on the site.

To produce the unique voronoi pattern, a script was created using the Grasshopper plug-in in the computer software Rhinoceros 3D. Figure 4-19 displays the script that was generated in order to develop the voronoi diagram in the Rhinoceros 3D. The script allows for designers to build generative algorithms to produce innovative and complex shapes within Rhinoceros 3D. Specifically, the script employs outputs to specific components, see Figure 4-19, and connects the components to the input of other subsequent components.

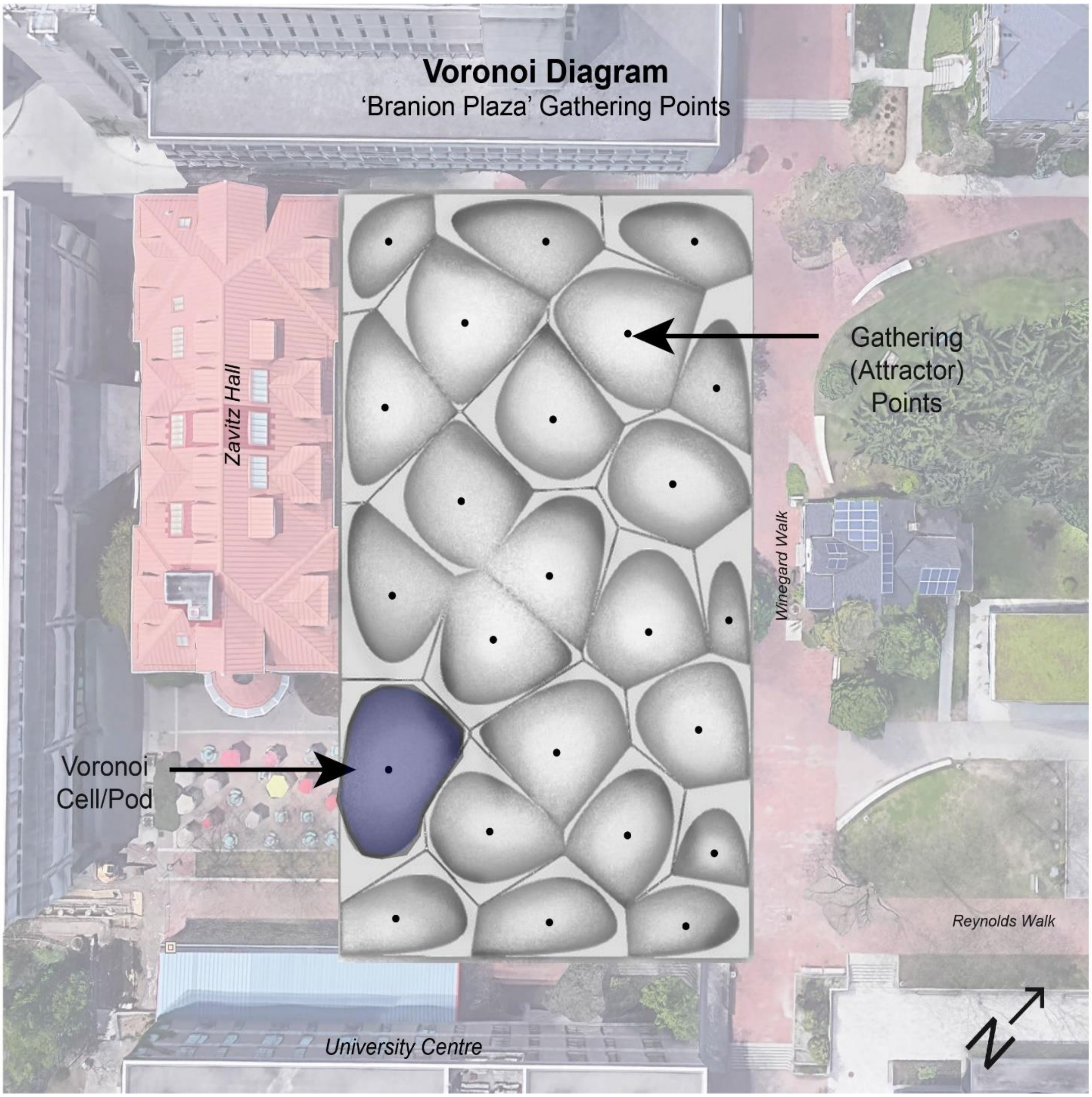

Figure 4-18 This illustration displays a digitally created voronoi diagram. This design application is used to understand the spatial relationships between gathering points on site. This image was created using Rhinoceros 3D with the Grasshopper plug-in (Source: Author).

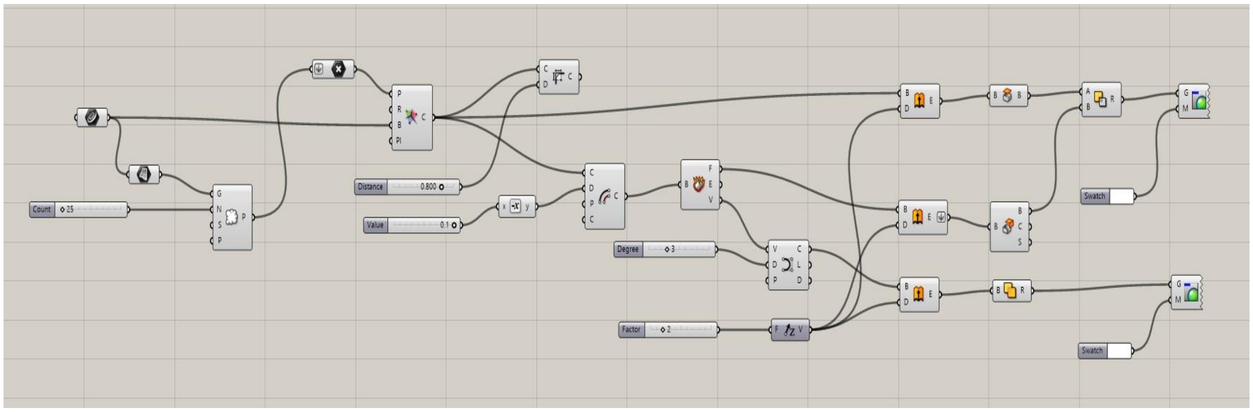

Figure 4-19 This illustration exhibits the script created to employ the unique voronoi pattern used in the digital design experiment. This script was created with the software Rhinoceros 3D using the Grasshopper plug-in (Source: Author).

The Grasshopper script is also useful for creating specialized functionalities in a design. Evidently, the Grasshopper script opens up a significant amount of potential beyond any of the standard components within Rhinoceros 3D and with using ‘traditional analogue’ design techniques in general. Although challenging to learn, using the Grasshopper script can open doors to more informative and detailed designs. Furthermore, utilizing this type of parametric technology is beneficial for conducting experimental designs, more specifically, using a ‘performative/experimental’ design approach for conducting analyses and overall designs.

4.7.5 Testing the Parametric Process: Voronoi Diagraming

To test the abilities of the Grasshopper script, an experimental design will be conducted. In other words, a performative/experimental design approach, as suggested by the case study comparative analysis, will be used to perform a variety of site scenarios. These scenarios will be geared to test the site’s spatial abilities and overall versatility and efficiency of the parametric technology.

Scenario 1: Densely Populated Site

Figure 4-20 displays a densely populated voronoi diagram based on one hundred gathering points. In this specific diagram, each attractor point represents one gathering point, therefore, indicating that one-person is standing at each given attractor point or within each individual voronoi pod. Creating a highly dense voronoi diagram can help determine the approximate volume of people a site can tolerate. As Figure 4-22 displays, the Grasshopper script can easily be manipulated to test a specific site scenario. In Figure 4-22, the highlighted component can freely be changed to test a desired scenario. In this example, the Grasshopper script was easily alternated to accommodate one hundred people. Certainly, this condition may not be realistic for the human experience. However, is does provide an understanding of a site's population capacity.

Utilizing parametric technology such as Rhinoceros 3D and Grasshopper can aid designers in testing for a variety of population densities. In this scenario, it was tested based on only one hundred people. However, due to the versatility and innovativeness of the Grasshopper script, designers can easily test for greater and smaller population densities for a variety of sites. In the specific experiment, the focus was only on 'Branion Plaza' at the University of Guelph. However, this technique can easily be applied to other sites. This design technique is does not only apply to one specific site.

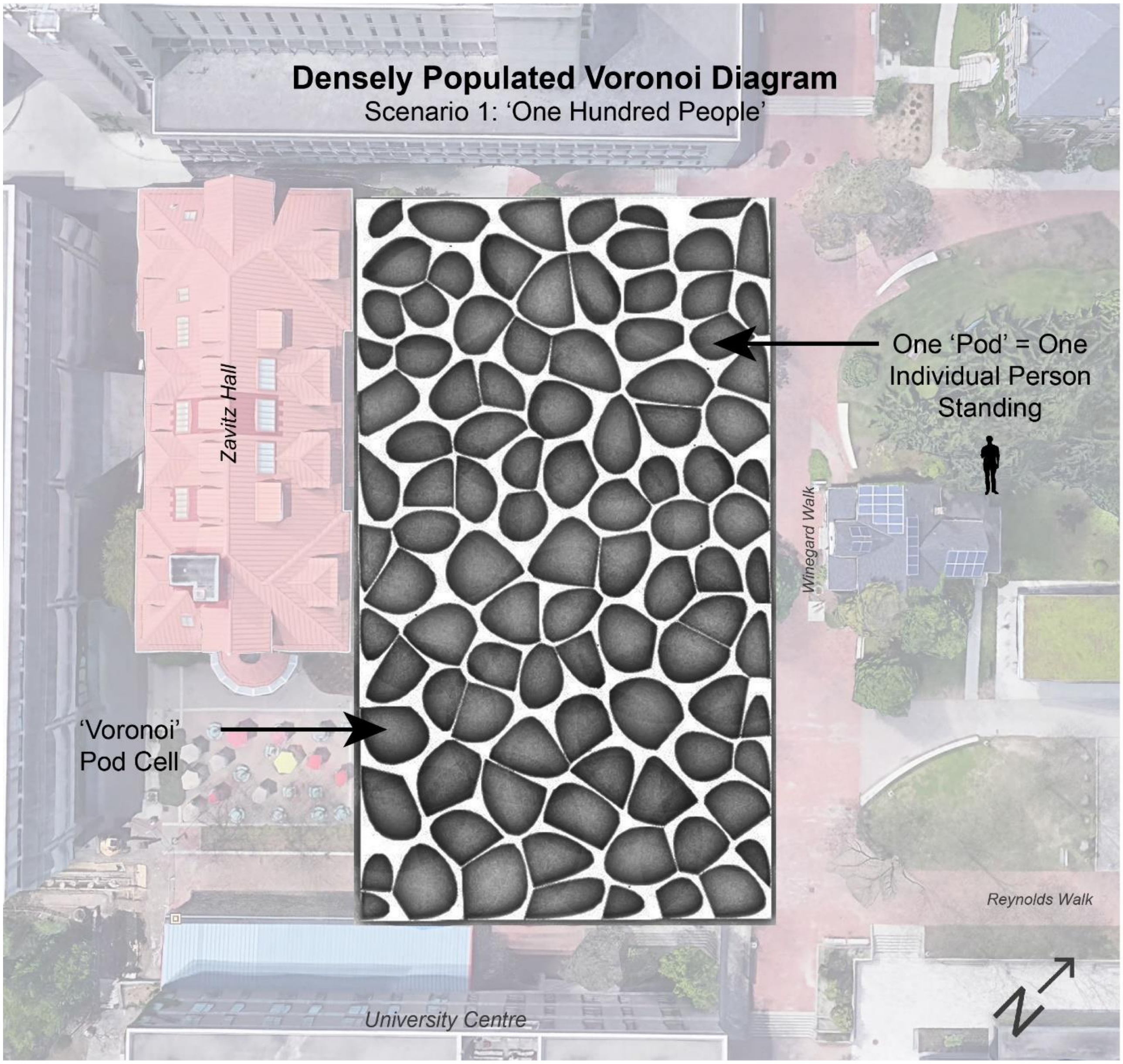

Figure 4-20 This is a rendered illustration of 'Branion Plaza', University of Guelph, tested for the spatial capacity of one hundred individuals using the voronoi diagraming approach(Source: Author).

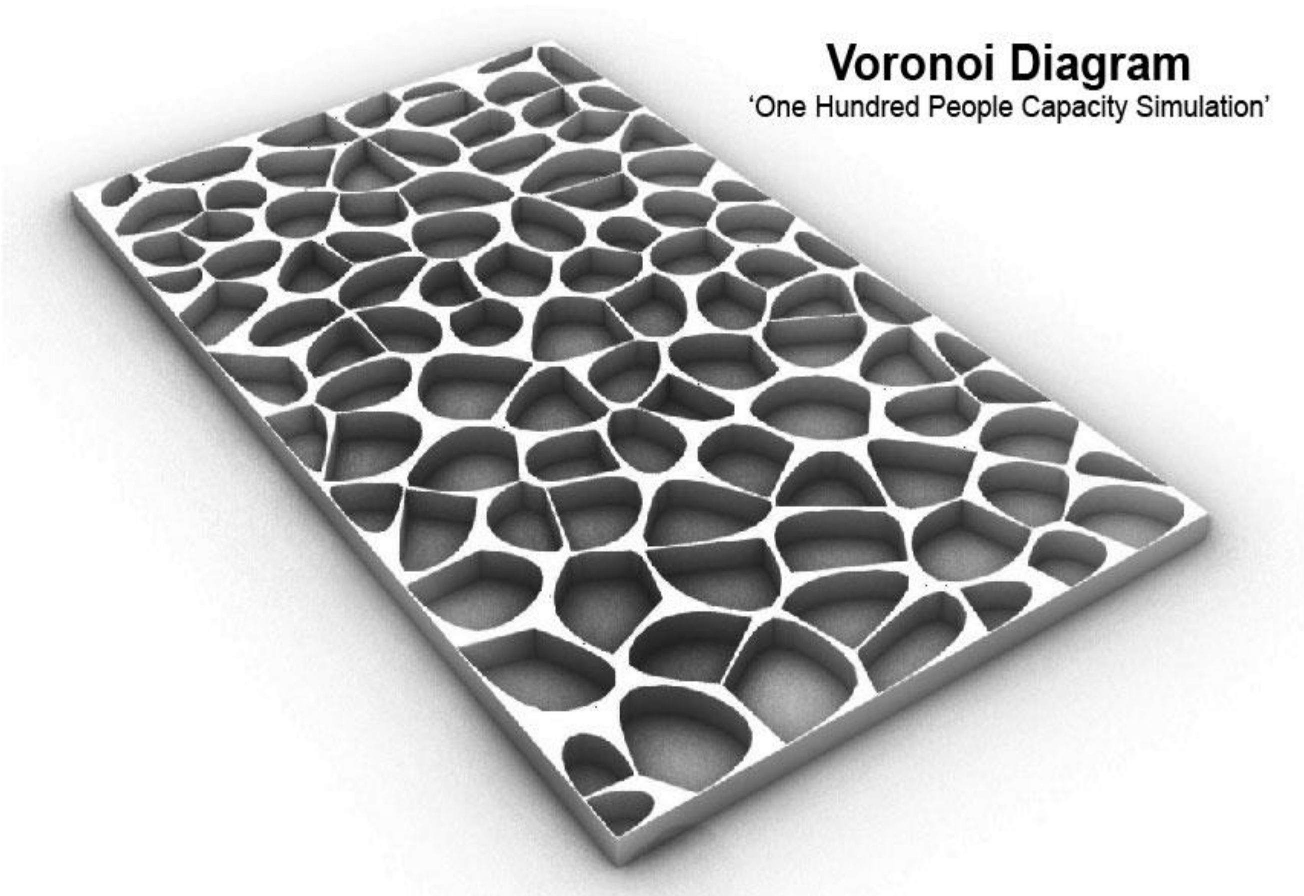

Figure 4-21 This is a render illustration of the 3D- prototype model of 'Branion Plaza' simulating one hundred people using the voronoi diagraming approach. This model was generated using the computer application software's Rhinoceros 3D and Grasshopper Script (Source: Author).

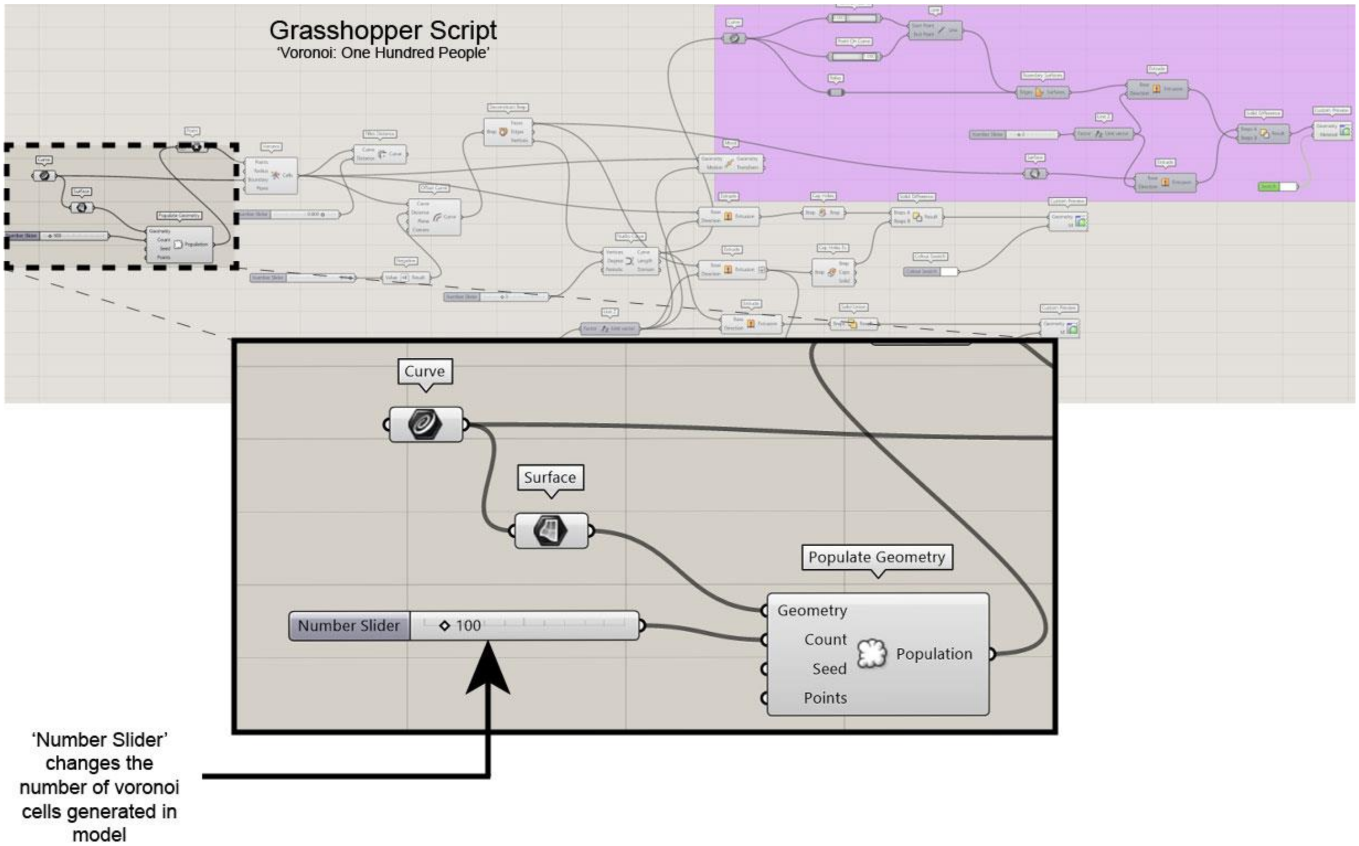

Figure 4-22 This illustration displays place Grasshopper script used to generate the voronoi cells for one hundred people. As the image indicates, the number of voronoi cells can easily be manipulated by change the number of voronoi cells using the 'Number Slider' component. The 'Number Slider' generates the number of points at the center of each voronoi cell generated in the model (Source: Author).

Ultimately, this is example of where parametric technology can efficiently aid in determining the appropriate and realistic conditions a site can endure. Therefore, using parametric design to employ a performative/experimental design approach go hand in hand. This technique of experimental design can benefit designer's in future situations as it can ensure designed spaces can continue be sustained and responsive to a variety of circumstances while also alleviating any room for failures.

Scenario 2: Social Distancing

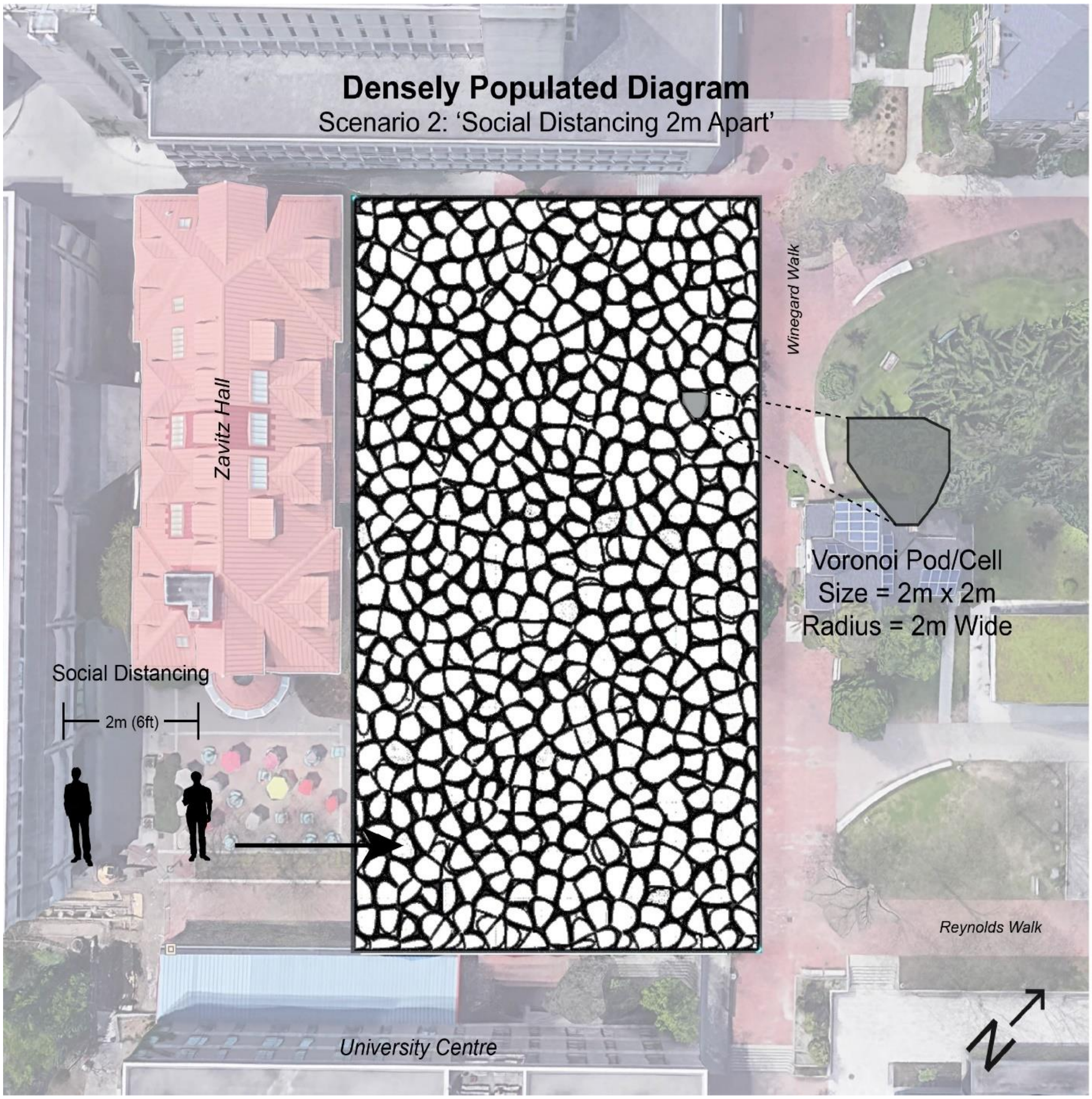

Figure 4-23 This is an illustration display a voronoi diagram testing for 'social distancing'. The size for each voronoi pod/cell is 2m by 2m wide. This safe measurement is considered the social distancing 'safe distance' for individuals to be around each other (Source: Author).

In light of the world's current conditions, this second scenario displays an experimental design designed for the intention of social distancing. Figure 4-23 illustrates a voronoi diagram with 'pod' dimensions of 2 meters (m) wide, giving a diameter total of 4m wide pods. The 2m by 2m wide distancing measures were based on the appropriate distancing individuals should follow to prevent the spread of illness. The appropriate 'social distancing' measurement that is suggested to follow is 6ft from another individual; in meters, equally to 2m apart. To generate these dimensions to the voronoi pods, the Grasshopper script must be manipulated to accommodate for these changes. Figure 4-24 illustrates the specific component in the Grasshopper script where the voronoi pods will be changed to become 2m by 2m's wide, following the fitting measurements for social distancing in a space.

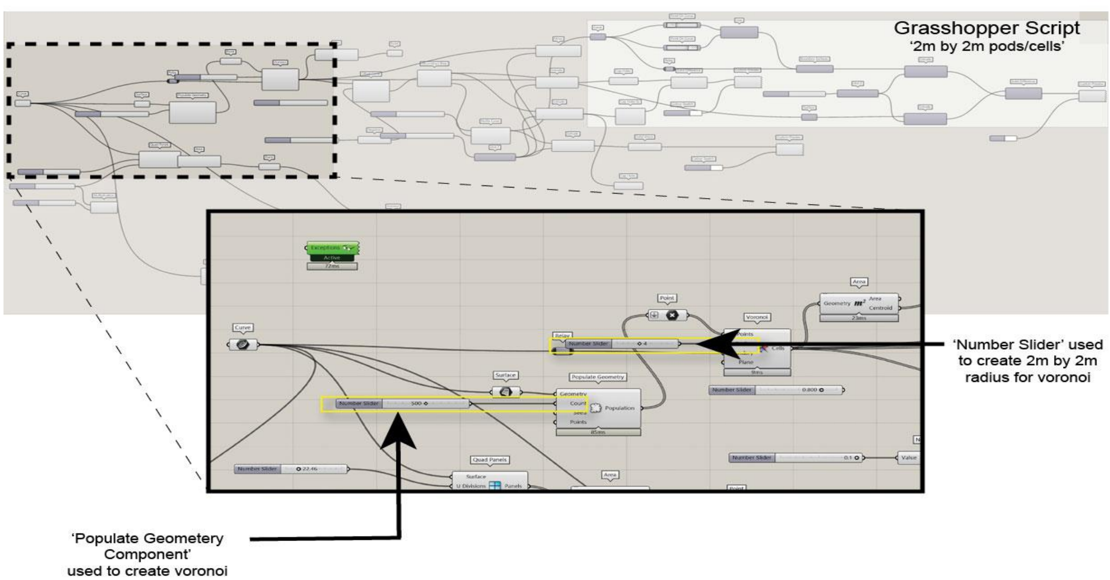

Figure 4-24 Grasshopper script displaying the specific components used to generate voronoi pods/cells sized at 2m by 2m. The highlighted 'Number Slider' is used to define the maximum diameter for each cell which then will be optimized to create the 2m by 2m voronoi cells. (Author: Source).

The dimensions of the pod sizes can be tested utilizing parametric technology to test the human experience during a contagion pandemic. The 2m by 2m wide voronoi pods were created based on providing the appropriate amount of safe space each individual person on the site should have. To elaborate, the 2m measurement is based from the center of one individual voronoi cell to its outside edge. Due to the organic form of the voronoi cell, this measurement of 2m can be adjusted more or less. However, the approximate diameter of each voronoi cell in this design scenario is about 2m wide. Evidently, the voronoi diagram in Figure 4-23 can provide an understanding of each pod's spatial relationship in proximity with each other; and further allow designers to understand whether this scenario is appropriate for the desired conditions of the site. Overall, this experimental design can inform designers on how to create a space that can ensure each individual in the space can navigate safety within the site. Testing with the voronoi approach has produces an overall unique and contemporary design, see Figure 4-25's perspective image.

Figure 4-25 This a rendered image taken from the 3D model generated in Rhinoceros 3D and Grasshopper. The model rendering displays a perspective image of a voronoi diagram displaying the appropriate pod/cell sizes for individuals in a 'social distancing' experiment (Source: Author).

Scenario 3: Designing for Open Landscapes

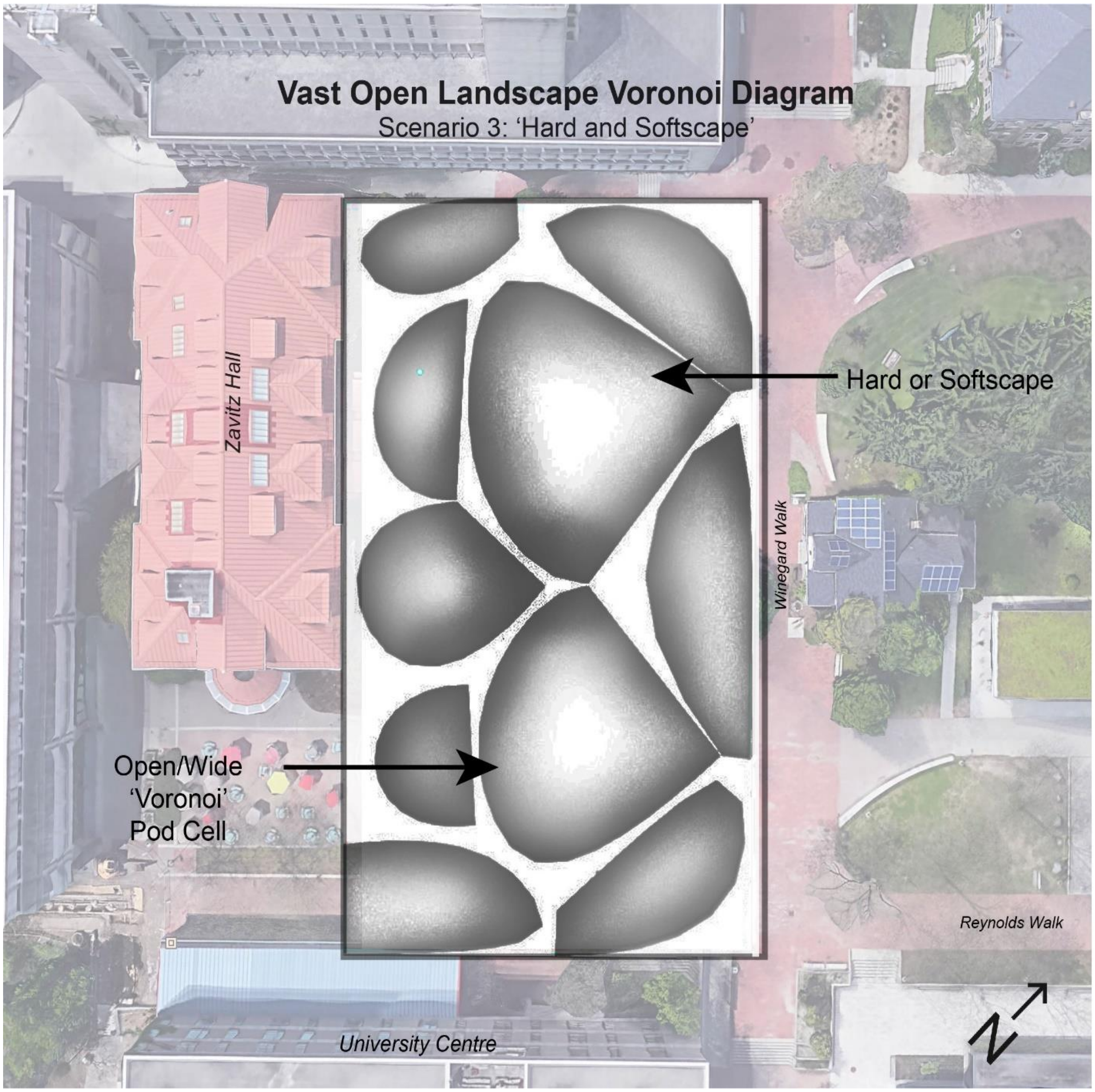

Figure 4-26 This is an image of the 3D prototype model displaying a scenario testing for large open spaces, specifically assessing the spatial relationship between hard and softscapes. This pattern was generated through a voronoi diagram approach using a Grasshopper Script (Source: Author).

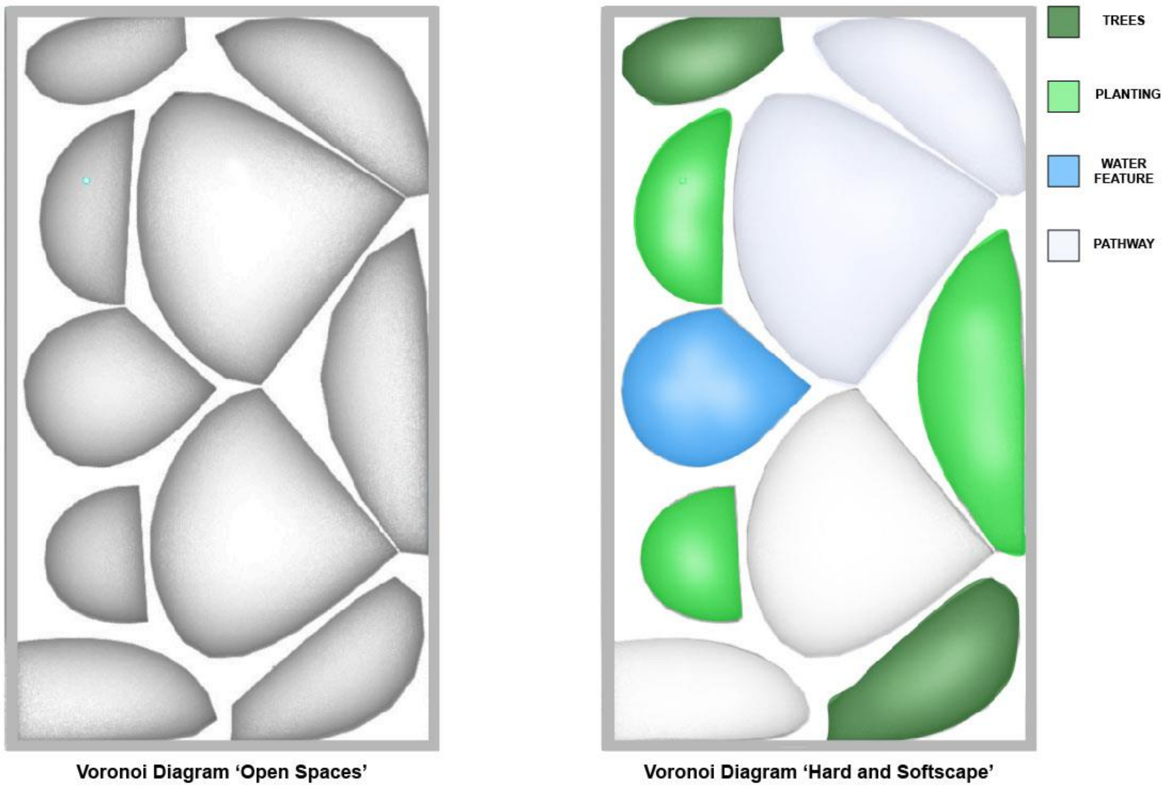

Figure 4-27 This illustration displays the analysis of utilizing voronoi diagrams for identifying appropriate locations for hard and softscape throughout the site. Using this method of analysis is useful for understanding the spatial relationship between site features (Source: Author).

The last scenario that will be tested is examining how to utilize parametric technology for designing open landscapes. Figure 4-26 and Figure 4-27 demonstrate how utilizing the voronoi diagraming method for determining the appropriate locations to place hard and softscapes on a site. Figure 4-27 provides a contextual diagram of 'Branion Plaza' using the voronoi pattern to display large open spaces. The benefit to using a voronoi diagram parametrically is that designers again can easily manipulate the space to attain a more thorough understanding of the relationship between hardscape and a softscapes spatially. Furthermore, a voronoi diagram is beneficial for mirror the environments natural conditions. Therefore, instead of trying to mimic natural features, designers can efficiently produce organic flowing designs that work well with a site’s current conditions.

For example, Figure 4-28 provides a conceptual rendering of the prototype model. This an example of an open spaced landscape which incorporates both hard and softscapes. Based on prior site analyses made in sub-section 4.7.3 in Figure 4-15, the current conditions at ‘Branion Plaza’ already contain hard and softscape. Evidently, by generating the similar voronoi diagram as shown in Figure 4-15 digitally with Rhinoceros 3D and Grasshopper, it was possible to account for these current conditions while also employing larger more open spaces. To expand, with the unique organic forms that a voronoi diagram can produce, a water feature and larger more open green spaces were incorporated. Figure 4-28 provides a hypothetical design scenario displaying larger and more open spaces than the current conditions of ‘Branion Plaza’. The rendered illustration demonstrates how using a voronoi diagram can aid designers in attaining a greater understanding of the spatial relationships between site conditions and features. On this note, this example exhibits how parametric design technology can easily manipulate a space to a different condition.

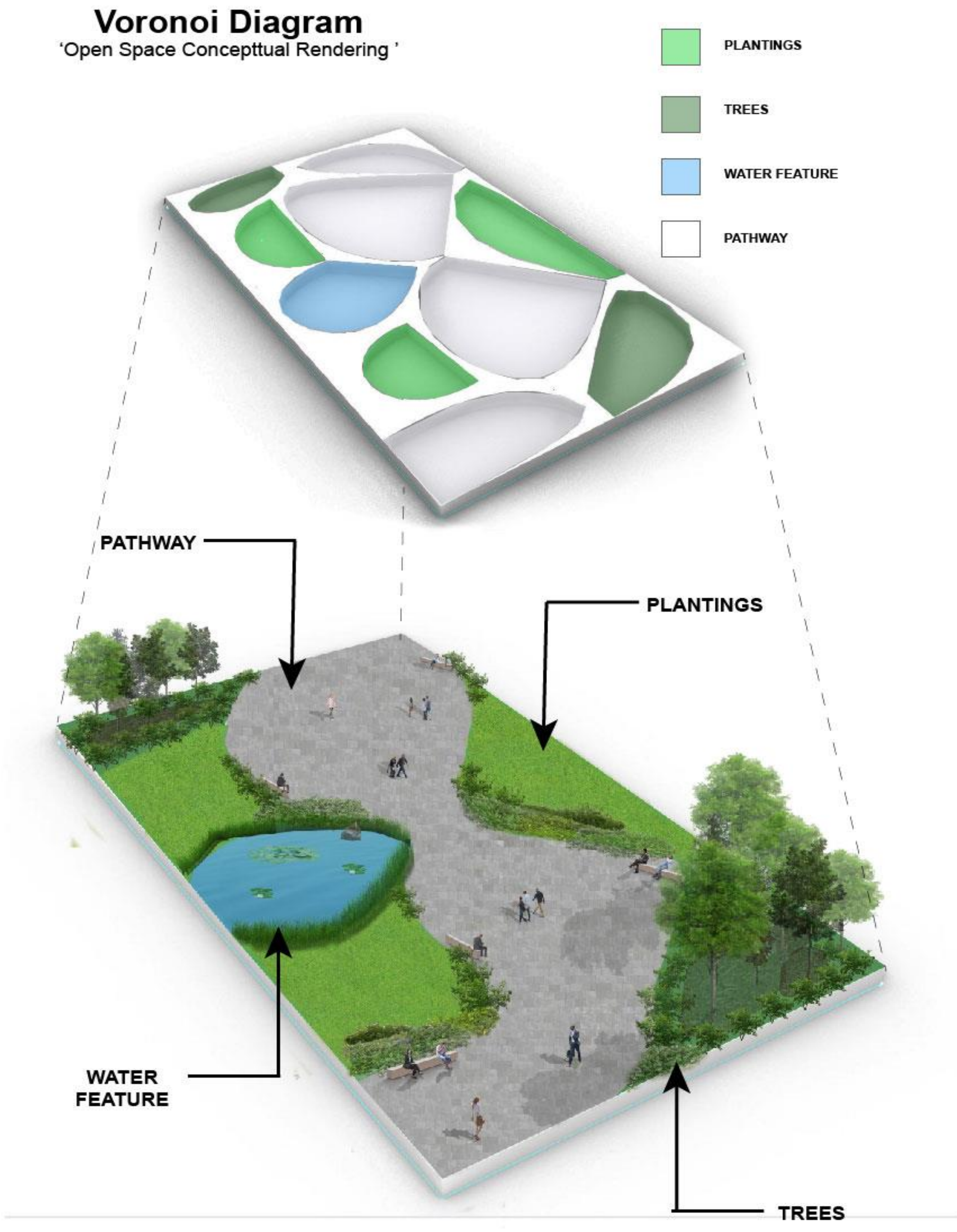

Figure 4-28 This is a conceptual rendering of an open space landscape using the voronoi diagraming method. This method of analysis enhances the ability to create natural organic forms with both hard and softscape materials (Source: Author).

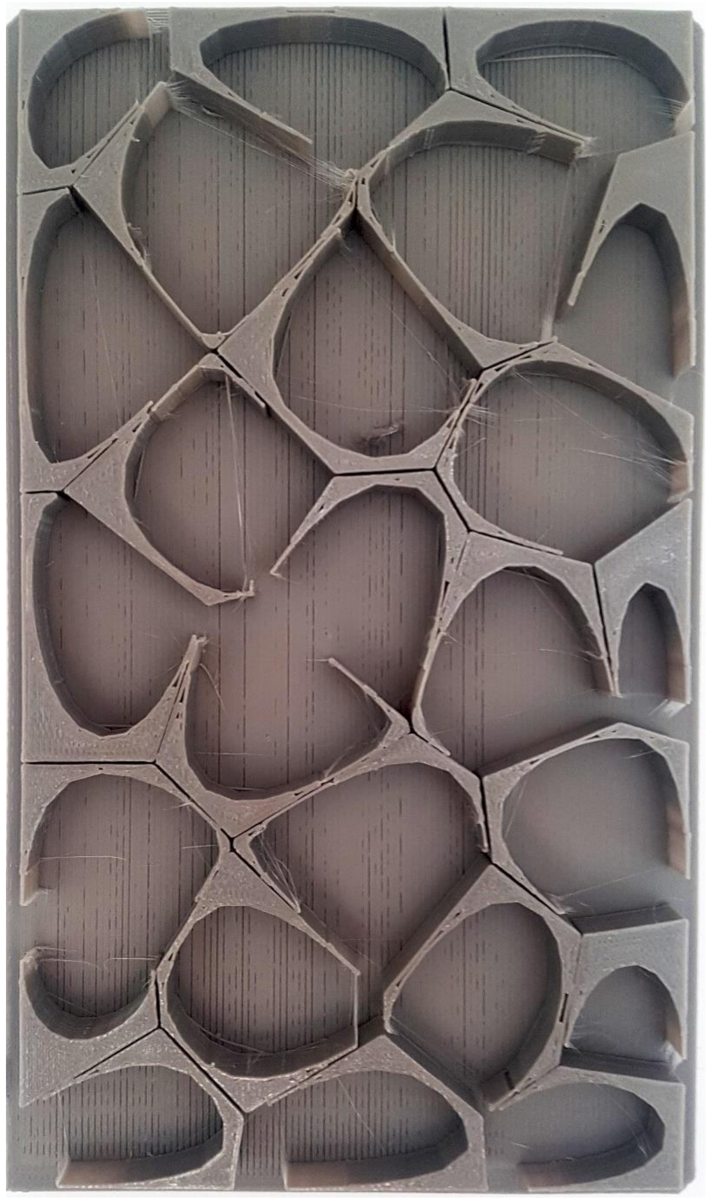

Figure 4-29 This is a top view image of the 3D printed copy of the voronoi prototype model. This model was printed from the University of Guelph's Digital Design Lab. This is an example of the versatility of parametric technology in terms of its capabilities of producing quick 3D prints directly from the Rhinoceros 3D and Grasshopper software's (Source: Author).

Figure 4-30 This is a perspective view image of the 3D printed copy of the voronoi prototype model. This model was printed from the University of Guelph's Digital Design Lab. This is an example of the versatility of parametric technology in terms of its capabilities of producing quick 3D prints directly from the Rhinoceros 3D and Grasshopper software's (Source: Author).

4.7.6 Testing the Parametric Process: Pathfinding s

The final test of the parametric process will focus on pathfinding and pedestrian circulation at ‘Branion Plaza’. The purpose of this analysis is to determine how or whether parametric technology can identify the shortest and most efficient pedestrian routes throughout the site. Attributing back to Figure 4-16 and Figure 4-17, where only traditional sketched techniques were used, designers can only attain a conceptual understanding of how to incorporate the most efficient routes for pedestrian circulation using that method of design. Furthermore, this analysis will demonstrate the versatility of parametric technology and its ability to skillfully determine the shortest most efficient routes.

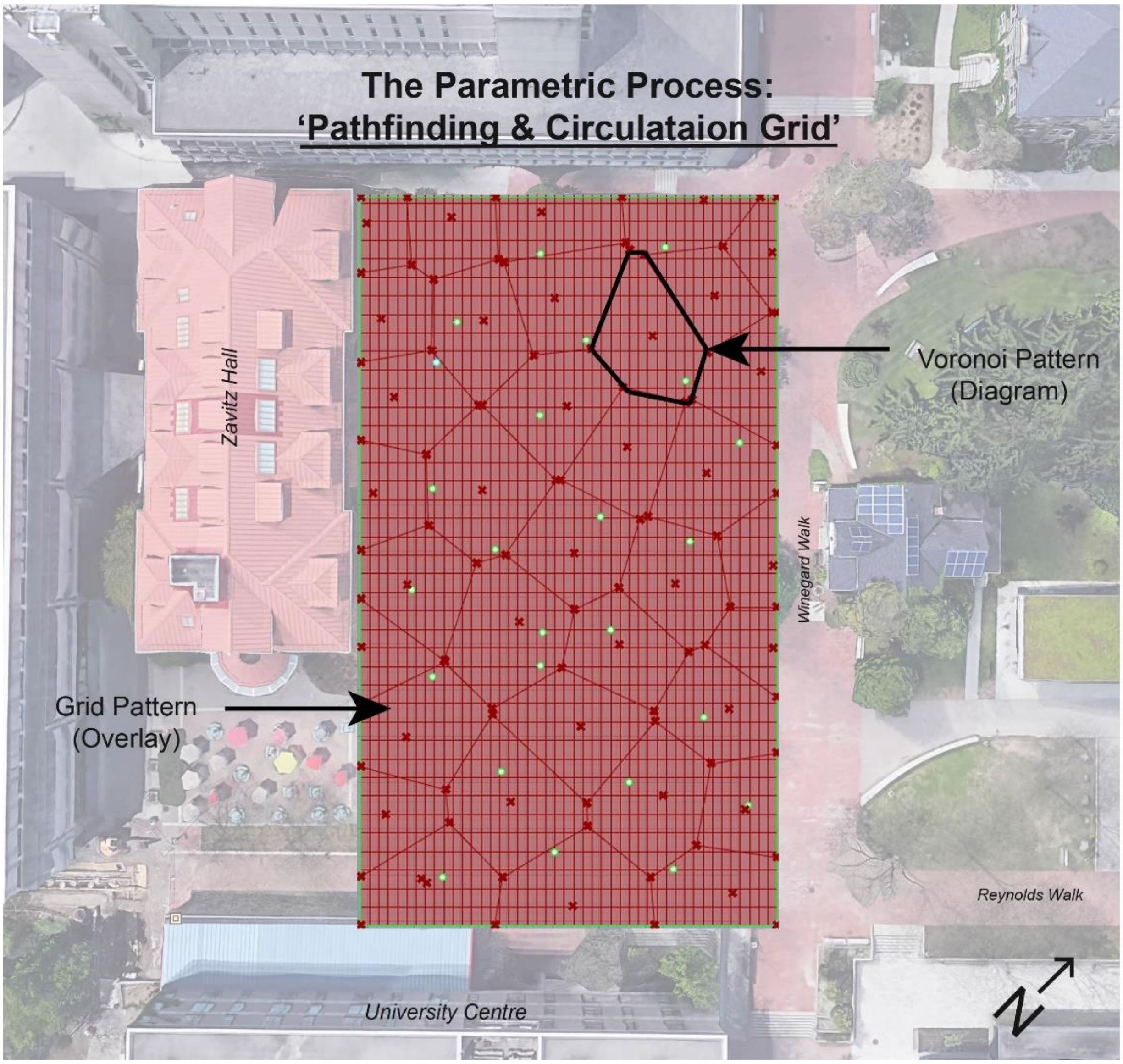

Figure 4-31 This illustration displays the grid and voronoi diagram used for identifying the shortest most efficient pathfinding routes for pedestrian circulation in 'Branion Plaza', University of Guelph. This pattern was generated using a Grasshopper script in the computer software Rhinoceros 3D.

Figure 4-31 provides an illustration of the digitally generated grid pattern overlaying the site's boundary and the continued voronoi pattern used in the previous spatial analysis test. By using the voronoi pattern to generate the path routes, designers can form routes that avoid obstacles on site while also determining the most optimal route. This grid was generated through a Grasshopper script where a pathfinding system can be applied to assess pedestrian circulation. To establish this script, two major components must be created; the overlaying grid following the voronoi diagram pattern and the pathfinding system. In Figure 4-32, this image displays the complex scripting input and output components used to generate this unique simulation. In Figure 4-32, the highlighted components feature where the grid and voronoi components for the pathfinding simulation are generated. Without these components scripted in Grasshopper, the experimental design will not be generated in the Rhinoceros 3D software.

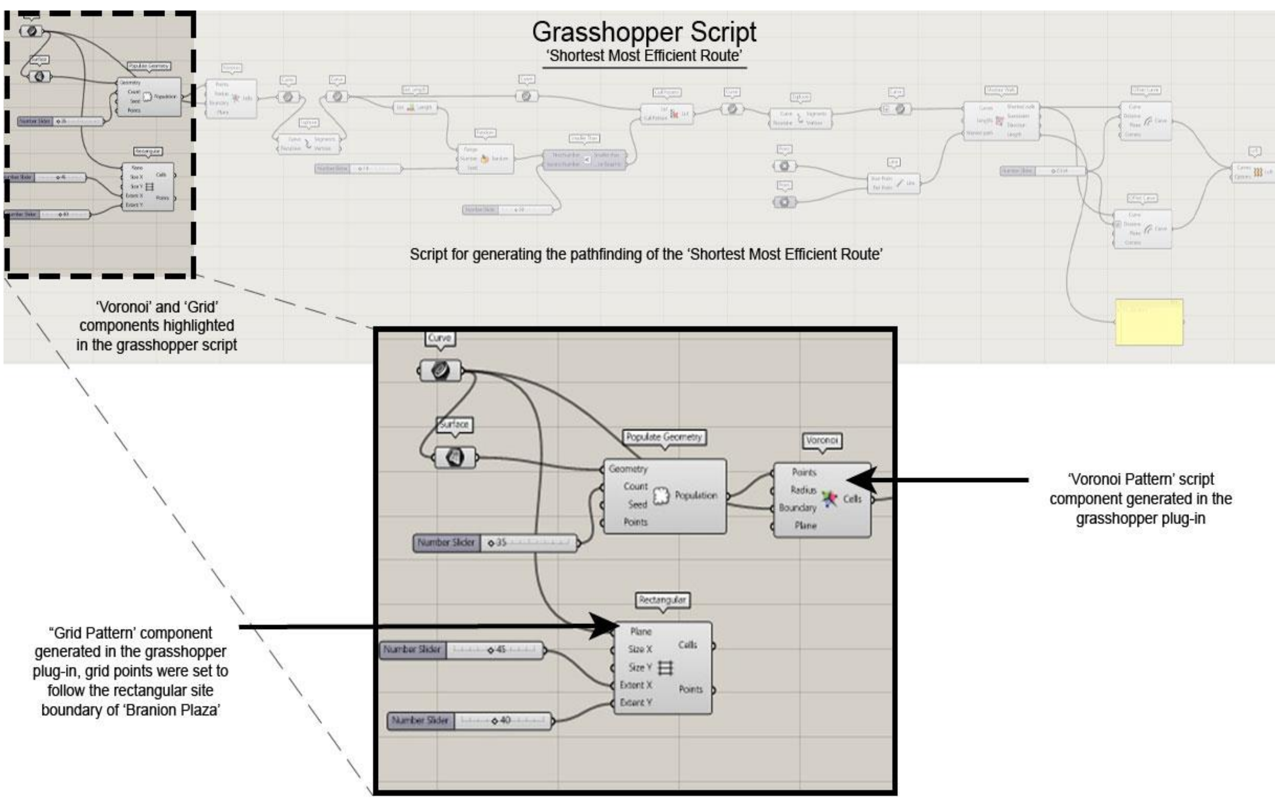

Figure 4-32 This illustration provides an overview of the 'grid' and 'voronoi' components in the Grasshopper script used to generate the pathfinding approach of identifying the shortest most efficient pedestrian routes on 'Branion Plaza'. The pattern this script generates can be seen in Figure 4-31 (Source: Author).

To simplify this, Figure 4-33 provides the general understanding of how the pathfinding script for identifying the shortest most efficient route is generated. In Figure 4-33 'point A' indicates the point in which an individual is standing. 'Point B' indicates the desired point of arrival. Furthermore, once 'point A' and 'point B' are given designated 'set points' within the Grasshopper script, a pathway is generated in a way to navigate an individual through the site in the shortest most efficient route possible. Evidently, 'point A' and 'point B' can be set to any attractor point throughout the site using the Grasshopper script. Therefore, the most efficient route can be determined regardless of where an individual is standing on the site.

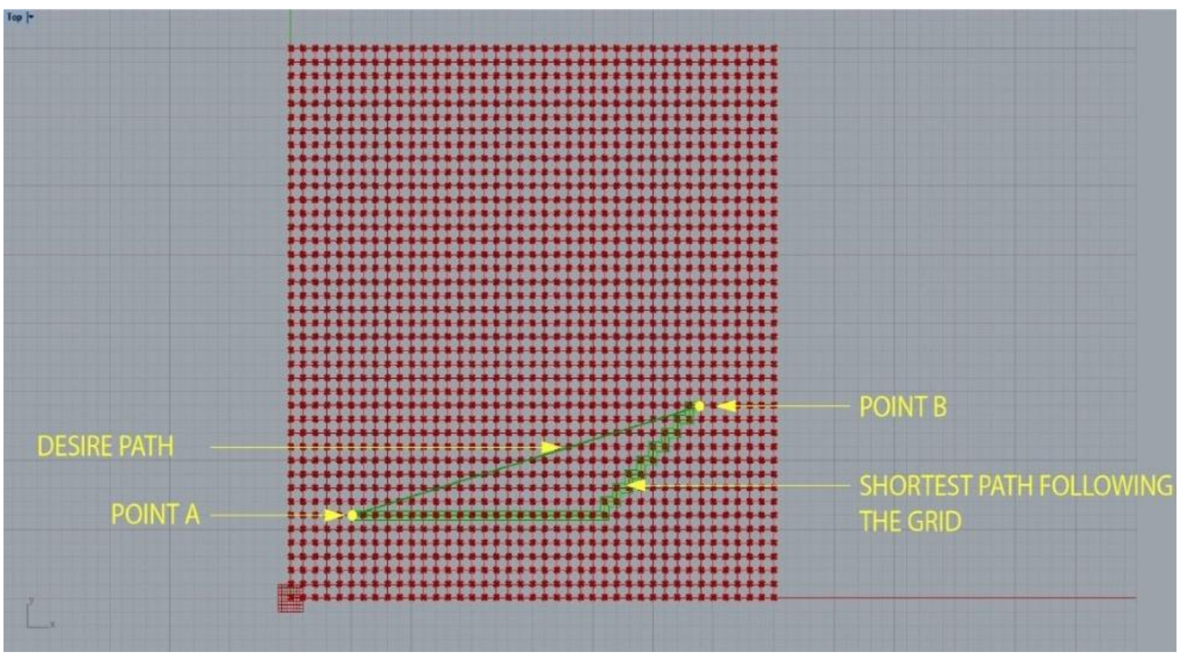

Figure 4-33 This illustration provides an overview of how the shortest most efficient component script works using the Grasshopper software. 'Point A' indicates the point in which an individual is standing. 'Point B' indicates the desired point of arrival. (Ashari, 2020)

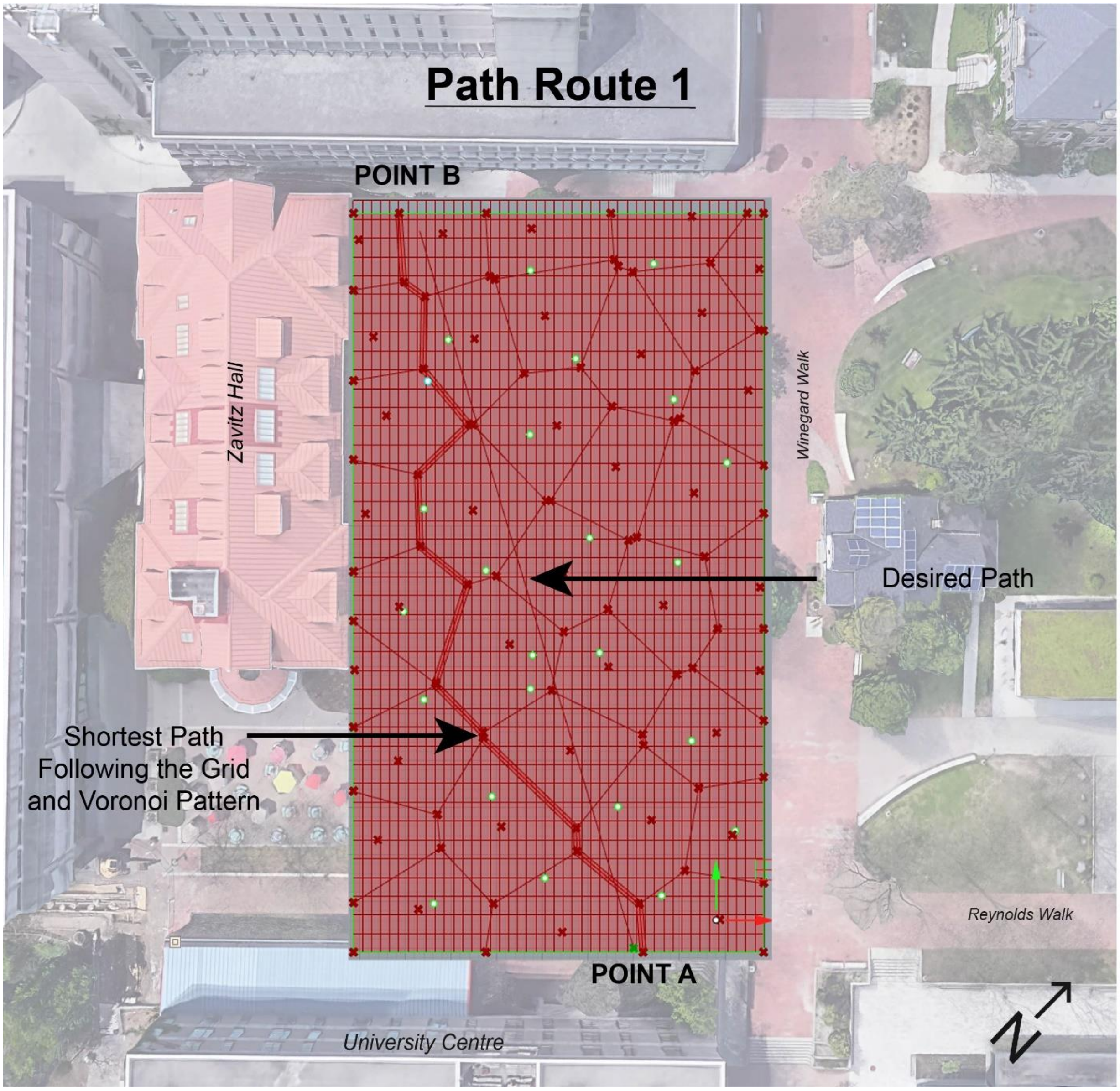

Figure 4-34 This is an illustration of the 'Path Route 1' which is testing the abilities of the Rhinoceros 3D and Grasshopper plug-in software's for determining the shortest most efficient pedestrian routes at 'Branion Plaza', University of Guelph (Source: Author).

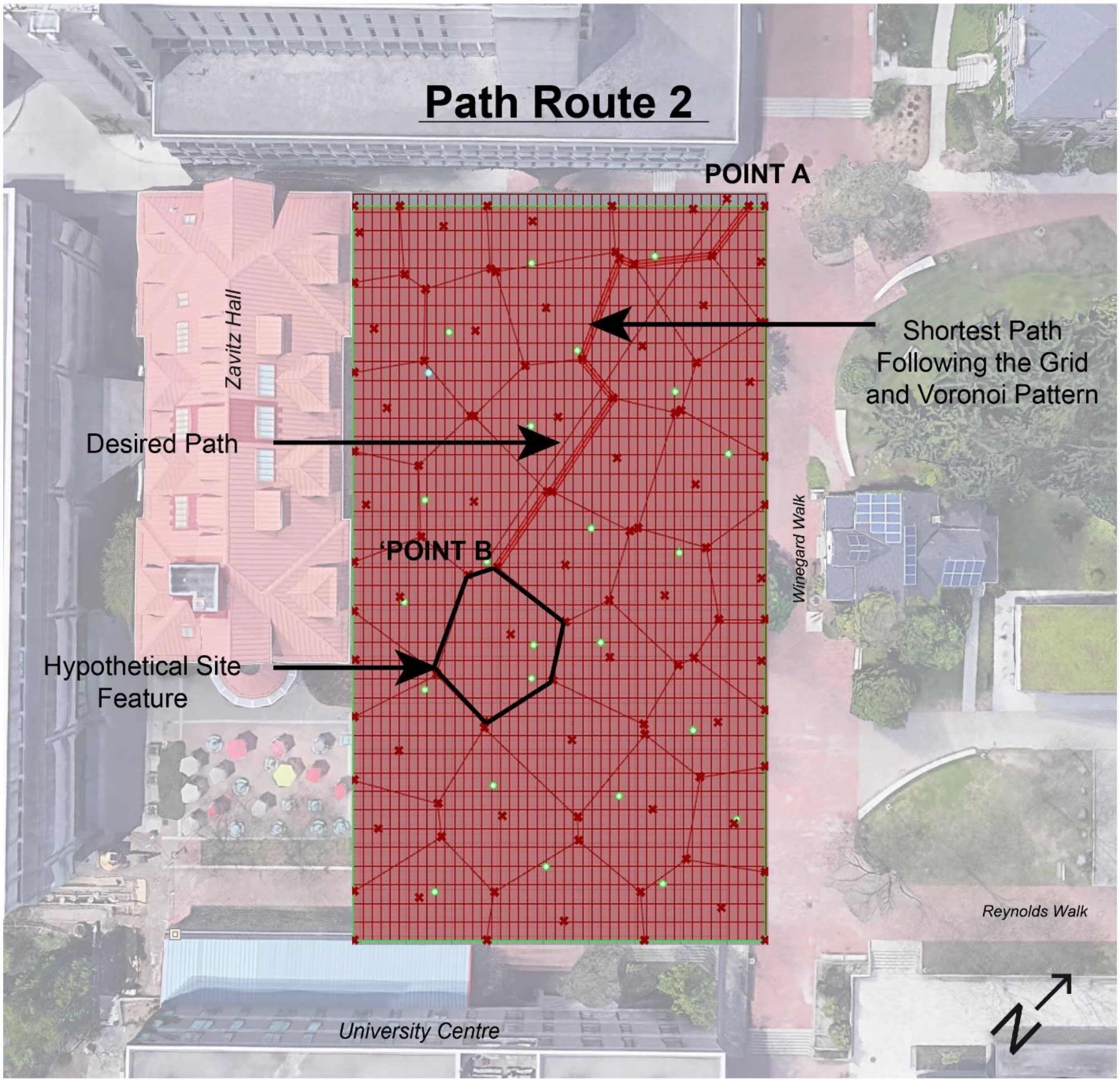

Figure 4-35 This is an illustration of 'Path Route 2'. Again, this is to test the abilities of the Rhinoceros 3D and Grasshopper computer application software's in terms of determining the shortest most efficient pedestrian routes at 'Branion Plaza', University of Guelph (Source: Author).

To test this, Figure 4-34 and Figure 4-35 provide two different routes for pedestrians to navigate through and across the site. Things to consider when conducting this is to be aware of site features and objects. However, in these two scenarios, for the purpose of only looking at the efficiency of parametric technology, the test will only focus on showing the versatility of the software for pathfinding from ‘point A’ to ‘point B’.

With this ability, a pathway can be generated between ‘point A’ and ‘point B’. This pathway will be generated through a Grasshopper script programmed to identify the shortest most efficient route. To apply this test, as Figure 4-36 displays, the pathway will be generated through a component called ‘shortest walk’. To generate this component, a grid map along with a voronoi pattern was created and overlaid on top of the site’s boundaries. By applying the grid, a designer can then set ‘points’ that represent ‘point A’ and ‘point B’. This can be easily done by inputting the ‘points’ components, as shown in the script in Figure 4-37. Evidently, the designer can set the two ‘points’ anywhere on the grid and then, by applying the ‘shortest walk’ component in the Grasshopper script, a pathway will be generated between ‘point A’ and ‘point B’.

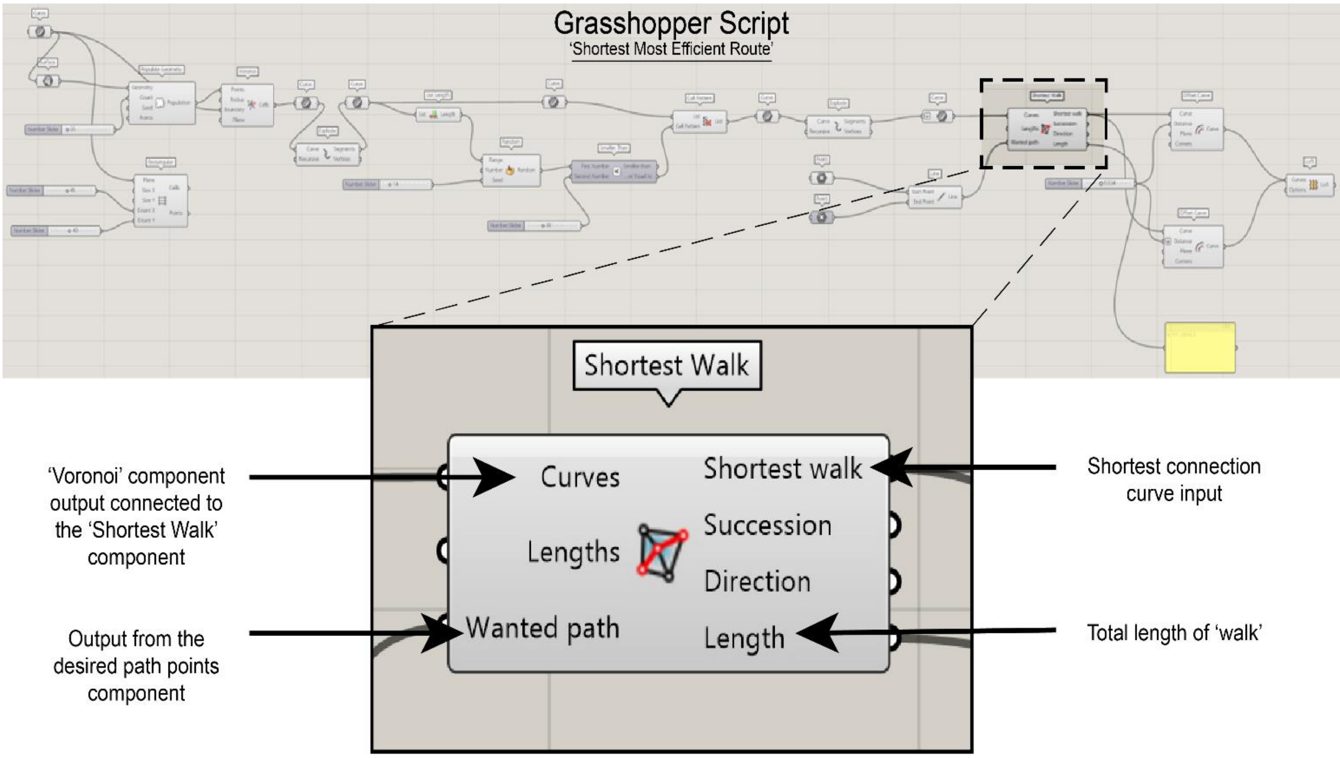

Figure 4-36 This illustration identifies where the 'shortest walk' component is located within the Grasshopper script. This component is what aids in generating the shortest most efficient pathfinding routes (Source: Author).

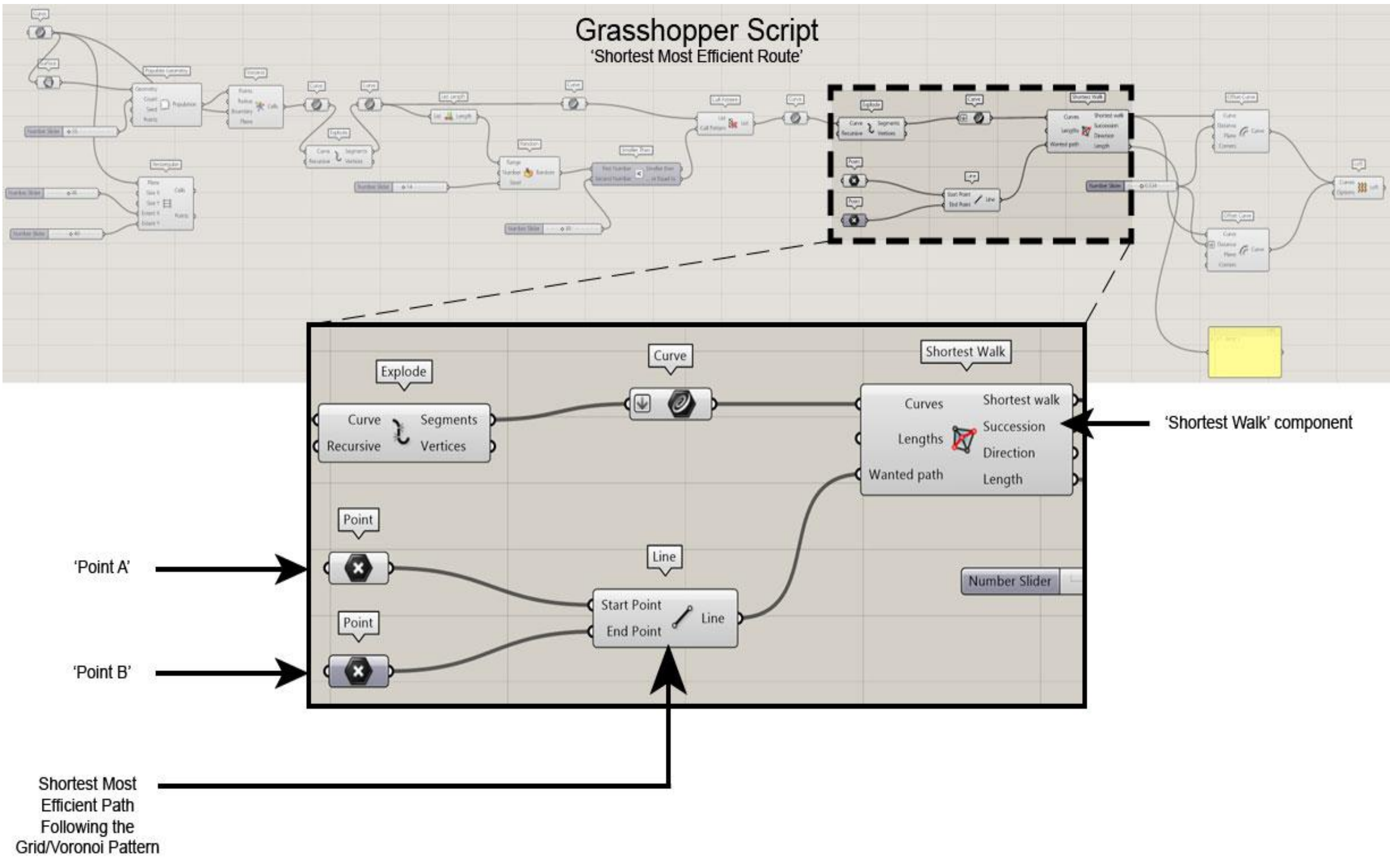

Figure 4-37 This illustration displays the location of 'Point A' and 'Point B' within the Grasshopper script. The outputs from the 'Points' components follow into the 'Line' component which generates the desired path. The 'Line' desired path output is then connected to the 'Shortest Walk' component to then determine the shortest most efficient route for the desired path to follow (Source: Author).

For example, Figure 4-34 displays a pathway beginning at the right bottom corner follow across the site and ending at the top left corner. Perhaps in this scenario, an individual is leaving the University Centre and travelling across 'Branion Plaza'. The algorithm of the 'shortest walk' component can then identify, by following the voronoi grid pattern, how to find the shortest most efficient route across the site. The second example, Figure 4-35, displays a pathway beginning at the top right corner of the site, following into the middle of the site. Perhaps in this example the individual is looking to find the most efficient route to a site feature in the middle of the site. Again, to determine this, the designer would set ‘point A’ to the bottom left corner where the individual is standing and set ‘point B’ to the middle of the site where the ‘potential feature’ is located. The algorithm would then apply this information and generate the most efficient and shortest route to that feature.

In conclusion, it is clear that parametric technology such as the computer application software, Rhinoceros 3D and the Grasshopper plug-in, can significantly aid designers in creating efficient and long-lasting designs. Although parametric software’s can be challenging to navigate, designers can apply the parametric process to enhance their designers in terms of versatility and for overall, producing unique visionary spaces.

5 Discussion

5.1 Overview

The observations found in the analysis and results section are presented in this chapter. The research findings to prior arguments and studies made by scholars in Chapter 2 are further correlated in this chapter. Furthermore, based on the analysis and results presented in chapter 4, a strategy is discussed based on how well parametric design technology performs on landscape designs in terms of promoting a more efficient design process and for executing resilient and innovative designs.

5.2 Performative/Experimental Design Approach

Through this study, the comparative case study analysis was used to investigate parametric design in terms of its efficiency in performance for landscape designs. In addition to this, the case study method was used to further understand how parametric design technology can contribute to creating innovative and unique designs that are versatile and resilient.

As stated in Chapter 4 section 4.5, using the research method of a case study comparison allows for the mobilization and accumulation of knowledge from each case study. Therefore, while comparing and contrasting each case study, new knowledge pertaining to the ‘parametric process’ was produced. For example, the information analyzed suggests that when utilizing the ‘parametric process’, designers should adopt a performative/experimental design approach for creating landscape designs.

The results from the comparative analysis suggest that using a performative/experimental design approach during the design process can enhance the ability to produce an optimal final design. For example, the results indicate that if designer’s test their designs through digital simulations, this can ensure a more efficient and resilient final product. This is because advance digital technology can account for a variety of scenarios; both human and environmental impacts. For example, parametric technology has the ability to test for spatiality, aesthetic, flexibility, responsiveness, and resilience.

The results from the comparative case study analysis also support the arguments made prior in Chapter 2 by Cantrell and Holzman (2016) and Zhang et al., (2017) in that parametric design promotes unconventional methods of design. Specifically, Cantrell and Holzman (2016) and Zhang et al., (2017) support the idea that those who utilize the 'parametric process' in designs are more likely to produce a more efficient final design. Cantrell and Holzman (2016) and Zhang et al., (2017) believe parametric technology offers more liberty in testing for optimal results. Evidently, leaving less room for human error and for an underperforming final design.

With the significant abilities parametric technology can offer, this does not suggest that it should be used over traditional methods of design. This analogy can be supported by the data collected within the questionnaire. Specifically, when the key informants were asked if they felt that parametric design hinders traditional design techniques, 80 percent of them agreed that it does not. Again, this supports the argument made by Cantrell and Michaels (2010); Pihlak (2004); and Ervin (2001) where they believe traditional analogue design plays a vital role in the application of digital design tools. Furthermore, it is fair to say that parametric techniques and traditional design techniques go hand in hand. Both tools of design are vital for employing a successful design. However, as this research has demonstrated, digital technology such as parametric design can enhance a design more thoroughly to ensure long lasting efficiency in terms of a design's versatility and responsiveness.

5.3 Addressing the Gap in Digital Design Technology

In terms of this research, the questionnaire was created to address the problem of understanding why there is a lack in digital design education, specifically with knowledge and skills training during schooling and in the landscape architectural practice. The questionnaire was also used to address the research problem of evaluating parametric design technology in terms of its efficiency in the design process and in creating landscape designs.

Significant themes to discuss from the questionnaire will focus on the gap between design education and in practice, whether parametric design is being implemented efficiently into the design process, assessing the user accessibility on parametric design software's, and its performance value on landscape designs.

As stated in Chapter 2, Schnabel (2007); Fischer and Herr (2002); Cantrell and Michaels (2010); and Love (2009), there is a gap in skills training and on knowledge pertaining to parametric design technology in both schooling and in practice in landscape architecture. Subsequently, the questionnaire addressed this argument and 80 percent of the key informants agreed that this is an issue in landscape architecture.

This begs to question why the key informants and the scholars in Chapter 2 believe this. This can be answered by observing questions 13, 14, and 16 in the questionnaire (see Appendix A). These three questions focus on the accessibility of navigating parametric software's, their user friendliness, and time management for creating landscape designs. Overall, the results imply that the key informants accept that parametric technology is challenging and there is a learning curb on how to use it appropriately and efficiently.

To expand, the questionnaire asked if parametric design was being integrated efficiently into the design process. The key informants answered with comparable results, indicating percentages of 55 percent answering ‘yes’ and 45 percent answering ‘no’. However, when asked whether they believed it is being integrated efficiently specifically for creating landscape designs, the results were significant. The key informants answered with a 75 percent response rate of ‘no’ indicating that parametric design technology is not being integrated efficiently into landscape designs.

With this information, we can identify that professionals in practice currently believe there is a gap in knowledge and training for parametric design technology in both schooling and in practice. The reason for this gap, as the questionnaire results suggest, is because the software is challenging to understand, furthermore, making it difficult for designers to use parametric technology efficiently for creating landscape designs.

However, parametric technology is highly used in the engineering and architectural practices. This possibly could be because advanced digital design technology like parametric software’s are taught more often in architecture programs than landscape architecture programs. However, alluding back to Love (2009)’s analogy where he explains that architectural programs at universities in the United States such as Ivy League schools like Yale, Harvard, Princeton and Columbia, have strongly incorporated parametric modelling, or digital scripting programs due to the increasing influences of parametric professionals teaching at these institutions. Architectural schooling programs do follow accredited standards made by the American Institute of Architectures (AIA) which in some cases, incorporates digital design applications. However, these guidelines can be vague and are interpreted by the institution. Evidently, Love (2009)'s analysis focuses primarily on Ivy League institutions in the United States, and furthermore, is not acknowledging all American architectural institutions.

Accordingly, while analyzing this study's questionnaire, specifically, to the question focusing on the performance quality of parametric technology for architectural designs, 82.6 percent of the key informants answered 'good' to 'excellent' to its performance. Although the questionnaire results suggest that the majority of the professionals believe parametric technology enhances the performance quality of architectural designs, this does not suggest this is due to an immediate correlation to what is taught in architectural programs.

Adverting back to the questionnaire, about 60 percent of the key informants believe parametric software should be used and promoted in the studio/school-based environment. Therefore, suggesting that key informants working in the landscape architectural practice currently believe it is important for young student professionals to be learning about digital design techniques. Perhaps with students being exposed to parametric design during their school process this would alleviate the gap between schooling and in practice in terms of digital design knowledge and applications.

This does not suggest that parametric technology is insufficient for producing landscape designs. Parametric design is present in landscape architecture, as the case studies and the literature review have demonstrated. Rather, it is a method of design communication that can allow designers to create beyond parameters by invoking innovative and experimental visual designs.

5.4 Efficiency in Landscape Designs

This research suggests that although learning parametric software's can be challenging, in terms of efficiency, parametric design can contribute to innovative, versatile, and resilient designs. This section of the discussion will discuss the different ways in which parametric design can promote efficiency into landscape designs.

5.4.1 Versatility

In terms of versatility, parametric technology has the ability to adapt or be adapted to several functions or activities that may occur within a site design. For example, this research has demonstrated in both the case studies and the design experiment, parametric technology can input a variety of simulations to test the versatility of a site. This can easily be done by implementing specific components within a Grasshopper script tailored to what a designer seeks to test in their design. For example, this was demonstrated in the design experiment in Chapter 4 sub section **Error! Reference source not found.** with pedestrian circulation where identifying the s hortest most efficient path route could be determined. Evidently, depending on how a designer creates a space, the Grasshopper script can easily be manipulated to change pedestrian circulations in an efficient manner to adjust to changes within the overall design. Other ideas to consider are that using these components, such as a voronoi diagram and pathfinding scripts, can easily be applied to other types of sites. This type of research does not only apply to a ‘one size fits all’ policy, rather it can be easily manipulated to fit any site shape and condition. This argument alone supports how parametric technology is versatile. Furthermore, this can lead to an overall more optimal final design during the design process and in real time when the space is created.

5.4.2 Innovativeness

A key strength that parametric software can perform is its ability to create unique and complex shapes in a matter of seconds. Specifically, parametric technology is a customizable system where designers are able to produce interactive geometry and workflows all with the help from scripted components. With this high degree of customization, designers can produce unique geometries and innovative fabrications; furthermore, having the ability to create beyond traditional parameters of design. Parametric design invokes a new form of thinking and offers designers more liberty with their creations. This should be embraced as it can enhance the overall efficiency of how a space functions while also offering visionary aesthetics. This analogy supports Fu (2018)’s argument where he believes the innovation behind parametric technology is so efficient because of its ability to model 3D visualizations; specifically, with its ability to accurately mimic real-life attributes that can then be easily manipulated to simulate a variety of scenarios.

For example, using the Rhinoceros 3D software in collaboration with the Grasshopper plug-in, designers can create customizable shapes and quickly produce a

3D rendering within the Rhinocers3D software. If changes are needed, the designers can easily make adjustments to the Grasshopper script and accommodate for what is appropriate for the design. The innovativeness parametric technology offers are its capabilities to produce creations that go above and beyond traditional design techniques.

For example, parametric technology can manipulate digital parameters to produce realistic 3D organic shapes. For example, in Chapter 2, sub section 2.4.2 and 2.4.3 parametric technology was used to create naturalized ‘biophilic’ and ‘blob’ architecture; both of which are models of architecture that mimic organic form. The software is able to produce these unique forms due to its ability to manipulate the parameters of a script. Evidently, the parametric software can take a parametric equation that is defining a set of variables, which hold a variety of different functions (the parameters), and apply a new equation to form different types of shapes or functions. Subsequently, the innovativeness behind all this is that an explicit parameter can determine a specific classification or function to a form or shape within a design. If a designer wants to create a strong geometric form such a 3D cube, the script that contains specific parameters for a cube form can easily be applied. Vice versa for creating a more organic free flowing form.

In concluding remarks, the innovation behind parametric technology is extraordinary. The technology is inventive and promotes new forms of thinking; furthermore, employing more thoughtful and contemporary creations to landscape designs.

5.4.3 Responsiveness

In current times, we are faced with on-going changes to the environment. Climate change is a very prominent issue that has an impact globally. In terms of the practice of landscape architecture, we have the ability to mitigate these impacts and to create designs that can respond to these changes. In particular, utilizing digital design technology such as parametric design can offer designers the ability to test their design in terms of responsiveness before constructing them.

As demonstrated in Chapter 4 in the Case Study Comparative Analysis, each of the three landscape architectural firms used parametric technology to test their designs in terms of responsiveness to environmental conditions. For example, the design firm Stoss used parametric technology for their design project 'Erie Plaza', to test its responsiveness to stormwater flooding on their paving surfaces and vegetation. With this ability, they were able to create a dynamic design that incorporated softscape vegetation suitable for flood tolerance and innovative paving surfaces that also can sustain flooding conditions. Evidently, without having the ability to test a variety of environmental impact scenarios on their site, the site could have potentially faced problematic issues with the overall design.

Another form of responsiveness parametric technology can test for is a site's capacity in terms of number of individuals a site can tolerate. For example, the responsiveness of 'Branion Plaza' was tested in Chapter 4, sub-section 4.7.5 for pedestrian capacity; specifically challenging the number of individuals the space can tolerate and assessing the space based on social distancing recommendations. This is beneficial for understanding the human experience. To expand, it offers designers the opportunity to account for the appropriate condition's individuals need on a specific site; therefore, ensuring a more optimal final design. Parametric technology allows designers to quickly and positively react to changes; this again reiterates a more efficient design quality. In concluding remarks, parametric technology aids significantly in creating responsive designs, specifically with accounting for environmental conditions and human interactions. With this ability, this inevitably leaves less room for human error and a more thoughtful and long-lasting design.

6 Conclusion

6.1 Overview

The final chapter has a summary of research, indicates the limitations that arose throughout this study, assesses the future of landscape architecture with parametric design and addresses the opportunities for future research on the topic of parametric design.

6.2 Research Summary

Parametric design is a complex computer application system that uses algorithms as its foundation that compute a variety of functions within individual variables (parameters) that are created by scripted input and output components. The technology has been highly used throughout the early 1800s and 1900s into present time, specifically in the engineering and architectural industries for producing innovative and contemporary designs. Although a challenging software to learn, parametric design is present in the landscape architectural practice, however, it is slowly emerging. Evidently, this research study was conducted to address the gap between schooling and practice in terms of digital design knowledge and application skills pertaining to parametric design while also evaluating the parametric technology in terms of efficiency for producing landscape designs.

To assess these research objectives, three research methods were chosen to effectively evaluate the study. A systematic case study comparative analysis was used to evaluate three landscape architectural firms who use parametric digital technology to create designs globally. With this analysis, it was identified that by using a performative/experimental design approach for creating landscape designs, this will aid in producing optimal final results. This is due to the approach's ability, while using parametric technology, to test for innovativeness, versatility, and responsiveness for landscape designs. To expand, the research suggests that by adopting this approach, designers can attain a greater understanding on spatial form and thinking, ecological performance, and its ability to produce visionary landscapes.

Following this, a questionnaire was created for key informants who are professionals in the landscape architectural practice. The purpose of the questionnaire is to grasp an understanding on how parametric technology is being used in practice while also learning about its efficiency in terms of producing landscape designs. Key findings from this research method indicate that there is a gap in training and in knowledge pertaining to digital design technology like parametric design. There is also an understanding that although the technology is challenging in terms of user friendliness and navigation, the technology has the ability to promote unique and complex geometry in a timely manner for landscape designs. The key informants do believe it is an effective method of design communication that also invokes innovative thinking that goes beyond traditional design parameters.

Lastly, a design experiment was conducted to test the performance of the parametric process against the ‘traditional analogue’ design process and to evaluate the efficiency and versatility of using parametric technology for landscape designs. A prototype 3D model was generated using the computer application software Rhinoceros 3D with the Grasshopper plug-in. A site location was chosen at the University of Guelph, ‘Branion Plaza’ where a site analysis was conducted. This analysis focused primarily on understanding the spatial relationships amongst individuals and objects throughout the site and assessing pedestrian circulation by identifying the shortest most efficient routes within the space. To conduct this analysis, a performative/experimental; design approach was followed to conduct a variety of scenario to test the spaces abilities. To expand of this, a voronoi diagraming method was utilized to attain spatial data and to test the relationships between the spaces within the site. This method was conducted by creating a data developed script in the Grasshopper plug-in. A second method of analysis was the pathfinding approach. The pathfinding method was also created using a Grasshopper script and used to determine the shortest most efficient pedestrian routes on the site.

In concluding remarks, this research study has provided a significant overview on the topic of digital design technology, specifically, parametric design in engineering, architecture, but more prominently, landscape architecture. This study has demonstrated that although parametric technology is challenging, it can provide versatile, responsible, and contemporary landscape designs. This sheds a light on promoting more thoughtful and visionary design techniques to the practice of landscape architecture.

6.3 Limitations

This section of the thesis will discuss the limitations that arose throughout the research study. The first section will discuss the challenges associated with using parametric technology.

6.3.1 Parametric Design: A Complex Technology

As demonstrated through this study, parametric design software is challenging to navigate. Utilizing the technology takes time and a thorough understanding of its mechanics are needed to use it to its full potential. As a researcher who is a novice to the realm of parametric design, it was a challenge on its own to perform an insightful design experiment. Parametric technology relies heavily on computer engineering mechanics such as coding and scripting. An understanding on these concepts would benefit users and designers for using the technology. However, tackling these challenges with parametric design should not deter designers, rather it should motivate them to further implore inventive thinking towards designs.

6.3.2 Reframing Key Informants

With the second research method, the questionnaire, one of the main goals was to evaluate the gap between education and in practice of landscape architecture in terms of using parametric design technology for landscape designs. One idea that could have also been incorporated into the research was to use university students who are in a landscape architecture program as key informants. With the current data from the questionnaire, only professionals in the landscape architecture practice were asked to answer the questionnaire. Perhaps attaining a perspective from university students could provide more insightful results.

6.3.3 Timeframe

With the time constrains of the Master of Landscape Architecture program, a limited site analysis was conducted to demonstrate the performance of parametric technology. As this research has demonstrated, this technology is versatile and can perform a significant amount of different functions. To expand off this, again, as a novice parametric designer, this also had an impact on time for conducting the design experiment. This study only focused on the performance qualities of conducting a spatial analysis using a voronoi diagram and pathfinding mechanism for identifying the shortest most efficient routes on the site. Furthermore, with extra time, a more in-depth site analysis could be performed to demonstrate more qualities and functions that parametric technology can achieve.

6.4 The Future for Digital Design Technology in Landscape Architecture

As this study's research has demonstrated, advanced digital design technology has been innovating exponentially over the past century. With this technology emerging into the practice of landscape architecture, it has the ability to continue to innovate the practice in terms of promoting unique and efficient landscape designs. By assessing the pattern of computer design technology, it is clear that advance design technology will continue to grow in landscape architecture and be a prominent tool in the design practice.

Specifically, parametric design technology offers a designer the ability to create beyond traditional methods of design. Evidently, this will encourage more thorough and informative designs. Utilizing parametric technology in landscape architecture will ultimately aid in producing long last designs that leave little to no room for human error. To expand, parametric technology also offers the ability to create unconventional contemporary designs that could not be conducted through traditional design conventions. Although we see this trend of exponential design technology, parametric design can collaborate efficiently with traditional design methods, in particular, during the schematic and conceptual design phases. In other words, traditional design approaches will continue to be a big component in the design process in the practice of landscape architecture. However, due to the increasing evolution of digital design technology, parametric design will become a more prominent tool in the practice, perhaps if and when the gap closes between education and practice in terms of digital design applications and knowledge.

Another aspect of parametric design that can influence the future of the landscape architectural practice is its ability to test for environmental conditions. For instance, due to the versatility, innovativeness, and responsiveness of parametric software's, parametric design could become a more prominent tool for testing landscape designs against climate change.

6.5 Future Research Opportunities

This research study has focused on the efficiencies parametric design technology can have on landscape designs and in general to the landscape architectural practice. This study could be used as a reference to future research on digital design technology, specifically, with parametric design. As this study has explained, parametric design technology can be used to test responsiveness and ecological performances. Furthermore, future research on this topic could focus on climate change, as this is an on-going topic and issue, and therefore, test the parametric process for environmental conditions and changes.

By investing more into parametric technology into the landscape architectural practice, landscape designs can better respond to future environmental conditions and potentially respond to possible environmental impacts. This can ultimately can enhance sustainability within landscape designs and while also promoting the importance of the landscape architectural practice in terms of its responsiveness for combating climate change.

6.6 Concluding Statement

In conclusion, digital design technology has and continues to have an impact on the practice of landscape architecture. With further research and the opportunity for young designers and current professional to learn about advanced digital design applications, parametric design has the ability to invoke innovative thinking and unique unconventional designs that have meaning. With the versatility and responsiveness of parametric technology, landscape architects and designers can combat and test for impacts before a design is constructed. With the innovativeness of parametric technology, landscape architects and designers have the ability to construct complex forms and functions that perform beyond traditional mechanisms of design.

To expand, further research on the topic of digital design technology, specifically parametric design, could focus on mitigation methods towards combating ‘Climate Change’. For instance, research pertaining to the parametric process could further test landscape designs in terms of responding to environmental impacts and responses. Evidently, parametric modeling is capable of testing a landscape design for current and future impacts. Therefore, this type of research could promote further sustainability within landscape designs while also advocating for the importance of the practice of landscape architecture in terms of mitigating ‘Climate Change’.

Overall, advanced digital design technology can be challenging to learn, however, we should not let these obstacles hinder its abilities to produce long lasting and efficient designs for both the human and environmental experience. Parametric design is an extraordinary technological tool that will let the field of landscape architecture evolve to promote the design of more thoughtful landscape.

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APPENDICES

Appendix 1 Descriptive Social Survey: Questionnaire (Source: Author)

QUESTIONNAIRE

Dichotomous “Yes or No” Questions

1. *Do you use parametric software for your landscape architectural projects?*

   YES or NO

2. *Do you think parametric design is being integrated/implemented efficiently into landscape architecture?*

   YES or NO

3. *Is parametric design being integrated/implemented efficiently into your design process?*
   YES or NO

4. *Has parametric design changed your firm's approach to design?*
   YES or NO

5. *Do you believe there is a gap between education and the working industry in terms of training for parametric technology?*

   YES or NO

6. *Do parametric software’s produce complex forms and designs more quickly than other methods of design?*

   YES or NO

7. *Does the parametric process hinder the traditional design process?*
   YES or NO

8. *Are you an educator in landscape architecture (teaching at a University) or the principal, senior staff in your firm?*

   YES or NO

9. *If you have answered YES to question 8, do you promote or utilize parametric software in the studio/ other school-based projects or professional projects?*

   YES or NO

Likert Scale (Rating Scale) Questions

10. Rate the performance quality of parametric technology in the design process.

1	2	3	4	5
Very Poor	Poor	Fair	Good	Excellent

11. *Rate the performance quality of parametric technology for landscape designs*.

1	2	3	4	5
Very Poor	Poor	Fair	Good	Excellent

12. Rate the performance quality of parametric technology for architectural designs.

1	2	3	4	5
Very Poor	Poor	Fair	Good	Excellent

13. Parametric technology is easy to navigate.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

14. Parametric software is user friendly.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

15. Parametric technology enhances workflow.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

16. Parametric technology enhances time management.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

17. The parametric process promotes innovative designs.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

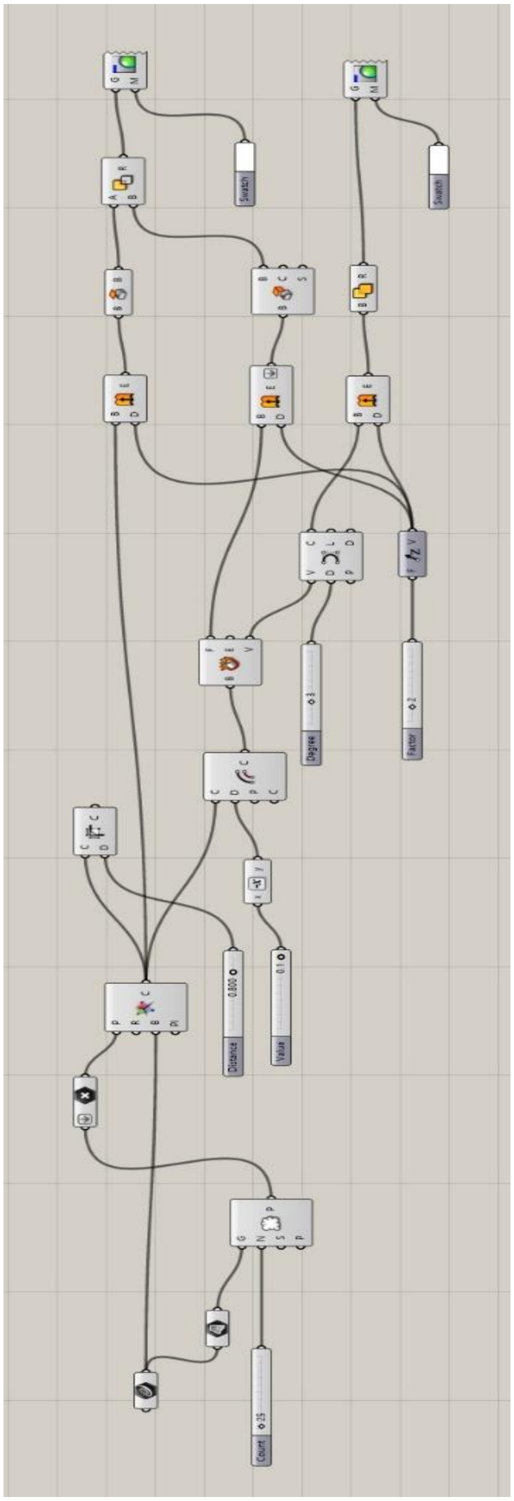
18. Parametric software produces complex forms and designs quickly.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

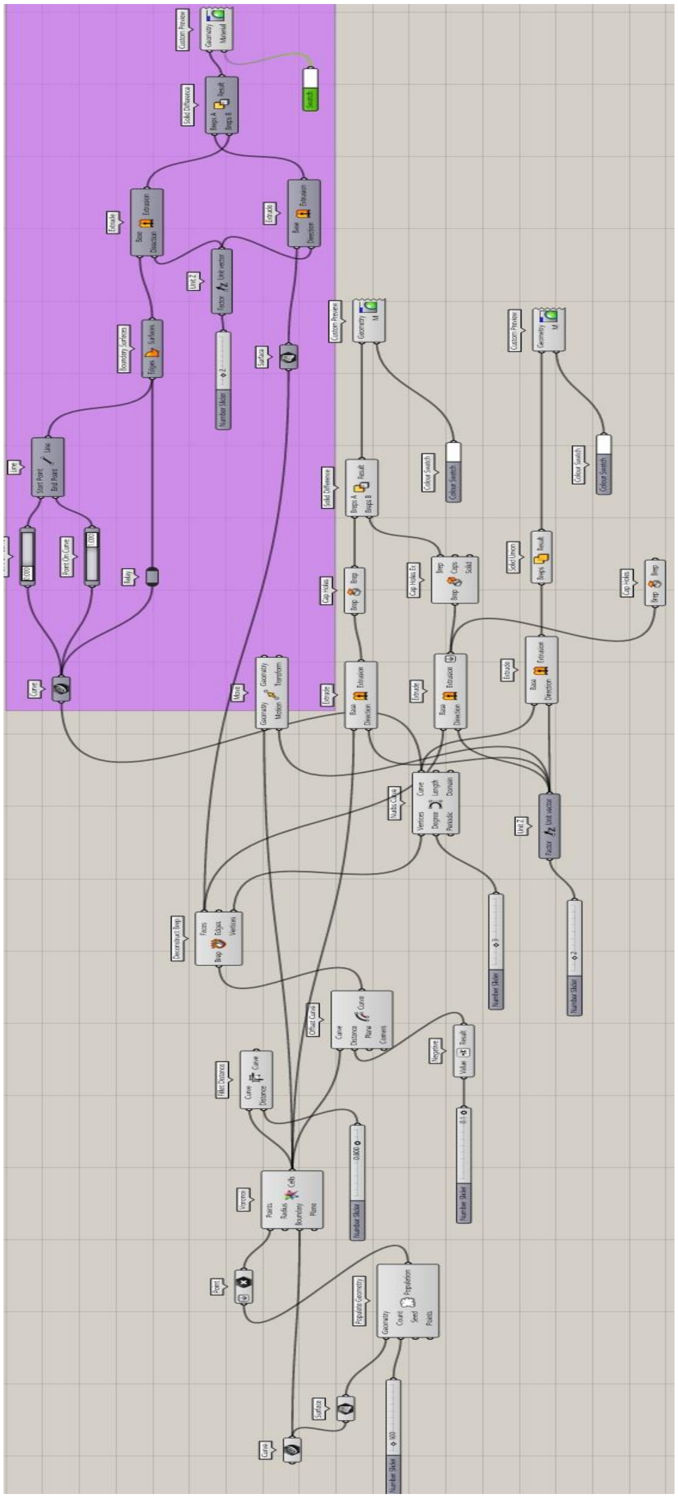
19. Please circle the software programs utilized in your office for modeling?

Rhino3D Grasshopper SketchUp AutoCAD Revit Other (please specify)

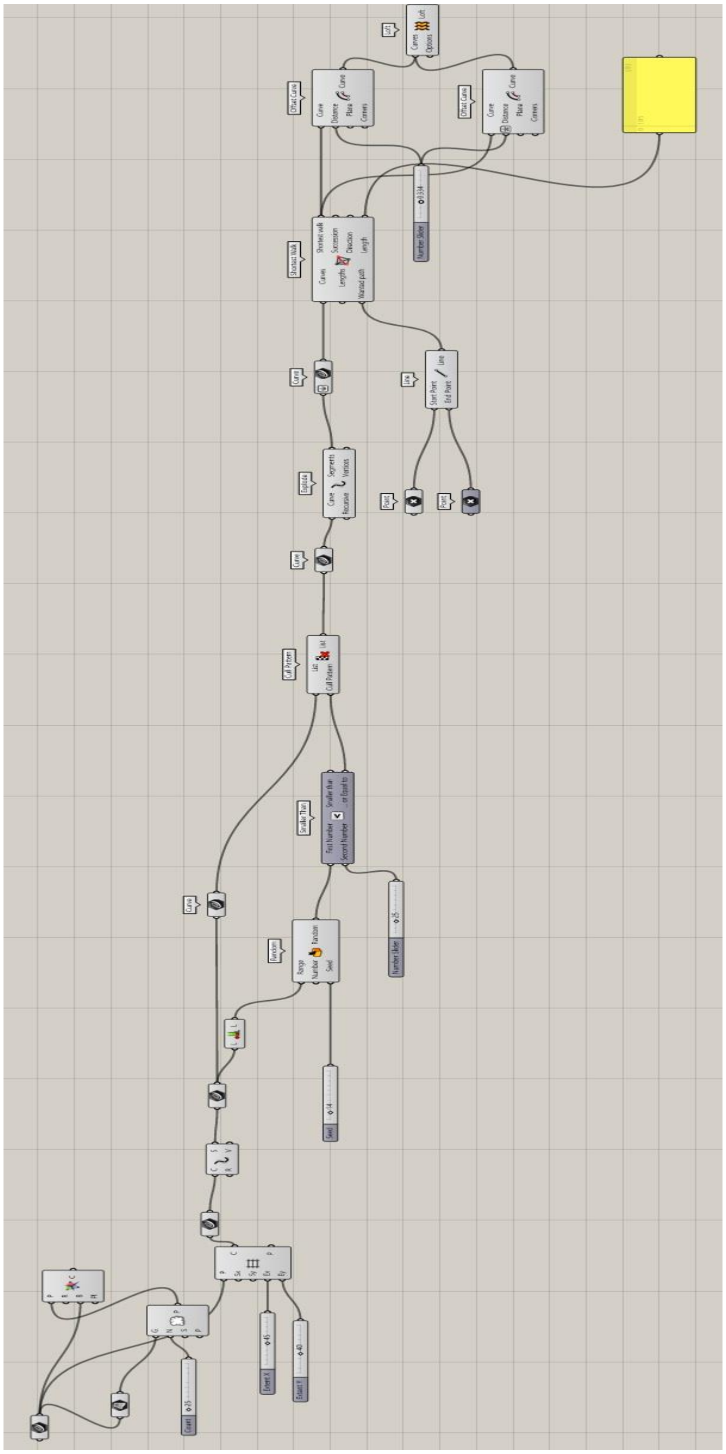
Appendix 2 Grasshopper script generating voronoi pattern (Source: Author).



Appendix 3 Grasshopper script displaying voronoi diagram for density of one hundred people and for simulating an open landscape. The voronoi cell sizes can be changed using the number slider (Source: Author).



Appendix 4 This is the Grasshopper script used to generate the pathfinding system for determining the shortest most efficient pedestrian routes (Source: Author).



Appendix 5 This is the Grasshopper script generated for creating voronoi cells sized at 2m by 2m wide radius to simulate a 'social distancing' experiment (Source: Author).