Generative Design in Landscape Architecture: Defining Three Design Scripts for Beginners

Afshin Ashari[1], Nadia Amoroso[2], Sean Kelly[3]

[1]University of Guelph, Ontario/Canada · aashari@uoguelph.ca
[2]University of Guelph, Ontario/Canada
[3]University of Guelph, Ontario/Canada

Abstract: Computational design has been utilized in landscape architecture for decades, and parametric design, a sub-category of computational design, has been gaining momentum in the field. Landscape architects are using parametric software programs to generate complex forms and to evaluate new spatial development. They aid designers in rapidly developing alternative designs to test complex forms and spatial designs. Key academics and practitioners of landscape architecture are implementing parametric design as part of their design process in generating various design scenarios. This study explores the current utilization of parametric design tools in landscape architectural practice and helps identify what basic functions may be important within landscape architecture education to aid students' understanding of these programs for design exploration. Inspired by the case studies analysis, three simplified ready-made design 'scripts' were provided to a novice student for experimentation with the generative design method.

Keywords: Parametric design, computational design, digital landscape architecture, teaching landscape architecture

1 Introduction

This study explores the current utilization and benefits of parametric design tools appropriate to landscape architectural practice. Three case studies are used to identify what may be important within landscape architecture education. In selecting case studies, the projects considered had to meet the following criteria: (a) utilize parametric applications and processes; (b) demonstrate parametric design and analyses; (c) were prepared and completed by landscape architects; and (d) were well-known and award-winning in the profession. The three projects selected as case studies were Xi'an Flowing Gardens by Groundlab (2011), South Park by Fletcher Studio (2017), and Little Island (Pier 55) by Heatherwick Studio and Mathews Nielsen Landscape Architects (2021).

These case studies will help answer with the following question: how can parametric design enable landscape architectural novice students to envision alternative designs, including spatial and environmental relations, by employing only a few ready-made scripts? The intent of this study is to explore the application of three design 'scripts' or algorithms to students with general 3D modelling knowledge, but little or no experience using parametric modelling approach. In this study, the student applied three scripts, inspired from the case studies, to a local campus plaza in order to test the ease and flexibility of these scripts in creating spatial forms and pathways suited for the design goals and the student's objectives.

Using these parametric scripts, the student could quickly experiment and test new pathways and space creations, including planting areas and open space gathering areas. The scripts were provided as modelling tools in parametric software. Grasshopper visual programming language was employed to run within the Rhinoceros 3D computer-aided design application, collectively

Journal of Digital Landscape Architecture, 7-2022, pp. 624-636. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-724-3, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537724058.

these provide the platform and tools to design a script. Furthermore, the student was able to quickly generate and experience several design alternatives that offer various opportunities for the site and the users of the space. Beyond the efficiency advantage, parametric design tools inspired the student and increased their engagement with 'generative' design approaches and technology.

Research suggests that there is a gap between skills, training, application of knowledge and utilizing the technology for parametric design (SCHNABEL 2007). By offering a novice student a 'toolkit' of three sample scripts for design generation, students could also be motivated to explore these tools further and gain intermediate parametric knowledge on their own. This toolkit will also investigate bridging the gap between the design process and designed medium (parametric software program), which are not reflected in more traditional computational design 3D modelling tools. This digital design approach is not intended to replace analogue or other traditional design processes, but to seek an alternative way to generate design forms and patterns using parametric software.

2 Parametric Design (Parametricism)

2.1 Defining the Parametric Design Process

Patrik Schumacher, Principal Designer of Zaha Hadid Architects, defines 'parametricism' as an avant-garde design movement that has been growing and maturing in the early 21st century with the development of advanced parametric design and computational thinking. This movement began in architecture but now encompasses all design disciplines, including landscape architecture, urban design, interior design, and fashion. 'Parametricism' has its origin in parametric design, which is a complex process that uses algorithms as its foundation and creates mathematical equations that encode different functions to manipulate design (GRANADERIO et al. 2013).

2.2 Parametric Design in Landscape Architecture

It is believed, "if a real threat exists for landscape architecture in the coming decade, it is that of being flattened and packed into a zoned-out 2D abstraction based on scientific methods belonging to another age" (CANTRELL & MEKIES 2018). Depending on the designer, many traditional design techniques utilized in landscape architecture today provide singular, or possibly few outcomes, to a design challenge; limiting the design alternatives and analyses may be generated. Parametric design provides a palette of possibilities offered by new computational methods.

With origins in architecture, and now influencing most design disciplines, including landscape architecture, parametric design can utilize various applications such as generative algorithms to provide complex geometries, data-driven analyses, form-modelling and analyses, algorithmic-based compositions, and optimization to address the concern for design homogenization. Currently, there is no consensus on the complexity of learning and applying parametric design in landscape architectural education.

The digital practice of landscape architecture and parametric design as a sub-category of this practice is gaining momentum. The next decade will be a critical transitional phase, which is expected to reflect the growth that occurred in architectural digital design practice (WALLIS & RAHMANN 2016).

2.3 Generative Design vs Parametric Design

The terms 'generative design' and 'parametric design' are often used interchangeably and often confused with one another (CAETANO et al. 2019). Both terms, in general, use algorithmic thinking as the foundation. However, Caetano, Santos, and Weitao (2019) extensive literature research on these terms addressed the modest definition differences. 'Parametric Design' is an approach that describes a design symbolically based on the use of parameters. 'Generative Design' is a design paradigm that employs algorithmic descriptions that are more autonomous than 'Parametric Design' (CAETANO et al. 2019). The generative design approach is a framework for combining digital computation and human creativity to achieve results that would not otherwise be possible (Autodesk 2019). Even from simplest algorithms, these approaches may create complex outcomes (CAETANO et al. 2019).

3 Three Generative-Designed Parks

The following section investigates three case studies that employed parametric technology and generative algorithms in the design and construction process.

3.1 Case Study 1: Groundlab, Flowing Gardens, 2011

Firm Introduction: Groundlab is an international design practice located in London focused on the fields of landscape architecture, urbanism, and architecture. Groundlab is currently led by the founding director, Jose Alfredo Ramirez, and co-director Clara Oloriz (Groundlab 2020). Ramirez is also the co-director of the Master of Landscape Urbanism at the Architectural Association in London. Groundlab uses generative design as a method of experimental modelling to create visionary landscapes and to test variable options for determining the best solution for urbanism in the future (AMOROSO 2012). Though this project is not so new, the parametric process used is still carried out today.

Project Overview: The Flowing Gardens are a demonstration of how digital design experimentation is a beneficial tool for design (BONAFEDE 2014). With working under time constraints, Groundlab used parametric digital technology to refine their elastic and adaptive working process (BONAFEDE 2014). The overall design was able to account for both Groundlab and Plasma Studio's objectives; a unified site was created, displaying a broken but interconnected mosaic between organic (landscape, flowerbeds, earthworks, and ponds) and geometric (structure, buildings, bent laneways and roads) design (BONAFEDE 2014).

Parametric Technology: The unique formation was designed using a 'Voronoi diagramming approach', an effective method for understanding a site's spatial relationship amongst its surrounding objects (Figure 1). This approach when a given set of points (Voronoi points) partitions a space into organic subspaces, setting proximity relationships among the set of points (PIRLO & IMPEDOVO 2012).

Using Grasshopper this approach allowed Groundlab and Plasma Studio to assess public connections with the surrounding organic landscapes more thoroughly, and to ensure the space could function efficiently. Voronoi approach provides a quick and efficient understanding of the relationships between objects within a given space. This process can involve the diagramming and indexing of the site to the 3d-modelling representation of the design. A major parameter inputted into the software was 'path generation' for specific viewpoints to a specific building, and the shortest path, adding the topography change of the ground. Using a parametric software, Groundlab was able to rapidly generate a series of possible scenarios that met their design goals. According to Ramirez, approximately ten variations were produced in a short period of time. They produced these iterations to meet client's revisions as well as coordination and response to necessities coming from surrounding projects (Ramirez, personal communication, August 24, 2021). Flowing Gardens was one part of a larger horticultural fair, and the coordination with other nearby architectural projects required constant changes throughout the process. The parametric tools and process helped the design group in rapidly making those adjustments. Groundlab utilizes parametric methods as standard in their office since many of their projects have short delivery timelines.

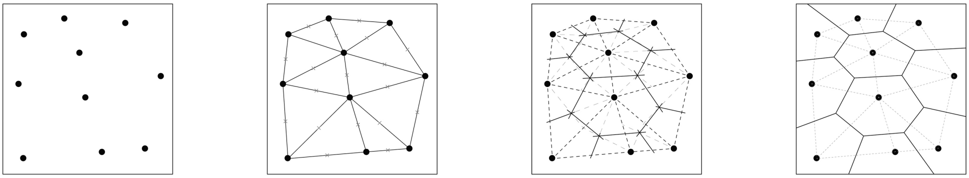

Fig. 1: Voronoi zoning offers the possibility to quickly adapt the zoning to the specific characteristics. Voronoi diagramming is used as a means of naturally partitioning a space into zones (PIRLO & IMPEDOVO 2012).

Fig. 2: Groundlab, parametric design technique for Plan of Greenhouse for the Flowing Gardens Project, X'ian, China

3.2 Case Study 2: South Park, Fletcher Studio, 2017

Firm Introduction: Fletcher Studio is a landscape architecture and urban design collaborative practice located in San Francisco, California. 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 2018). David Fletcher, the founder of the firm, teaches design studio at the SCI-Arc and Cal Poly. Fletcher Studio often designs parametrically using software programs such as Rhinoceros 3D, Grasshopper, and Rhino script to test complex forms, functions, and site layout (Amoroso 2012).

Project Overview: Fletcher Studio was selected to reimagine San Francisco's oldest public space (Figure 3). The new design is described as a contemporary interpretation of the picturesque style (Cantrell & Mekies 2018). The award-winning design allowed the space to transition from an English strolling garden to an integrated multipurpose community space (Fletcher 2021). The collaborative efforts of neighbours, city agencies, and private partners were integral to creating a unique design for the park. The park was finished in 2017 and is now universally accessible because of rigorous circulation and topographical considerations (Fletcher 2021).

Fig. 3: The Illustration by the students displays 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

Parametric Technology: The formal design decisions were primarily influenced by the goal of retaining a hierarchy of circulation patterns, access points, social nodes, and existing trees and structures (Cantrell & Mekies 2018). "In the initial design phase, these decisions were made through intuitive understanding of the parameters of the site and embedded in an analog rule set that guided design decisions. In further research, Fletcher Studio codified the relationship between the spatial logics of the design and the material logics of the tectonic, in a parametric algorithm." (Cantrell & Mekies 2018). In utilizing the parametric tools, Fletcher Studio was able to replicate the design process and distribution of access points and pathways with a distinct tectonic. These placements were mapped using Grasshopper, linking the access points to a single path as part of the design criteria. Using Grasshopper, Fletcher was able to generate a series of pathway options, allot optimal areas for play and those for planting. "The design of the park utilises a 'path finding' tool which uses data collected on site to draw the path towards important areas" (Groundhog 2017). According to Fletcher, "grasshopper was used to develop a responsive 3D working model, integrating the site data including existing utilities and topography. Paving tablet width, length, and distribution could be quickly adjusted by modifying inputs, allowing for site specific adjustments." (Fletcher 2020). Using Grasshopper, as a parametric technology software, and employing generative algorithms, the design process was more efficient. For example, twelve park design variations, eight play structure iterations, and fourteen wall and paving variations (Figure 4) were all generated in a short period (Fletcher 2021). The multiple design iterations of park and landscape elements would have taken a much longer time to create without the use of parametric technology. The algorithm also captured the ever-changing construction documentation, which made this process efficient in terms of time and accuracy.

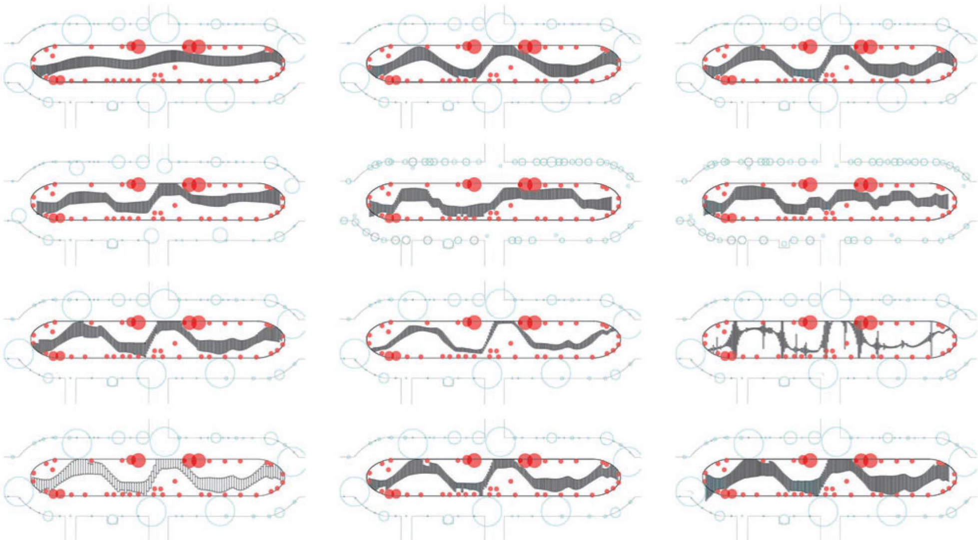

Fig. 4: The design of the park utilises a 'path finding' tool which uses data collected on site to draw the path towards important areas. Image: (https://www.fletcher.studio/south-park).

3.3 Case Study 3: Little Island, Heatherwick Studio and MNLA, 2020

Firm Introduction: Heatherwick Studio is located in London and is founded by English designer and artist, Thomas Alexander Heatherwick, who is known for incorporating innovative methods in engineering and materials of public installations (Heatherwick Studio 2021). Mathews Nielsen Landscape Architects (MNLA) is a New York-based firm founded by Kim Mathews and Signe Nielsen in 2014. As the prime consultant of this project, MNLA promotes ecological design solutions and integrated communities through place-making and inspired transformation of landscapes (MNLA 2021).

Project Overview: MNLA collaborated with Heatherwick Studio to design Little Island (formerly Pier 55), an iconic 9700-square meters (2.4-acre) public park in the Hudson River that brings together art and nature in an immersive experience. The pier geometry represents a floating leaf in the water as a unique topographic monument (Figure 5). The design provides resilience against climate change and celebrates a dynamic open space (MNLA 2021).

Parametric Technology: Heatherwick's team developed a few design repetitions using parametric design to achieve Little Island's creative design, which features irregular, unique, and complex curved surfaces (FARNSWORTH et al. 2020). Similar to Flowing Garden, the designer team used parametric modelling tools to implement the Voronoi grid system to generate multiple design solutions (Figure 6). This approach distinguishes the design geometry from other pier structures and presents it as an iconic and distinctive public space. This complex geometry was extremely challenging to convey via conventional 2D and 3D documenttation without employing parametric design software and method. For example, the designers and engineering teams used parametric programming to address all the structural calculations associated with the weight of the concrete piers (FARNSWORTH et al. 2020). The custom scripts developed in parametric design tools produced more design solutions in an automated process that expedited the calculations of each form and simulated a 3D representation of the design (FARNSWORTH et al. 2020). The parametric process helped MNLA select and situate the plantings in a way that avoided significant load on the concrete structural system.

Fig. 5: Little Island by Heatherwick Studio and MNLA. Image: https://www.cnn.com/travel/article/little-island-new-york-city-trnd/index.html.

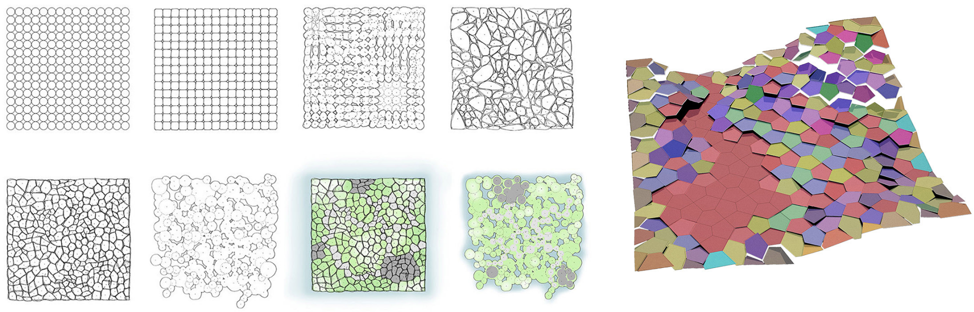

Fig. 6: Parametric design allows for rapid design iterations and expedites the design process. Image: http://www.heatherwick.com/project/pier55/.

4 Student Adaptability

The case studies used generative algorithms by utilizing 'Voronoi grid systems', 'pathfinding', and 'attractors' tools in the scripts. Inspired by the case studies, the research team provided a student with three simplified generative algorithms or 'scripts' to generate concept design iterations to be applied and tested on a local campus plaza design problem. These scripts were explicitly designed for beginner students to experiment with the process. By changing the sliders input parameters, the student could run the predefined algorithms, which generated various concept design solutions in a 3D model environment in real-time.

4.1 Voronoi Grid System

The student used a ready-made Voronoi Grid algorithm to test a few conceptual forms and compositional arrangements. With the ongoing Covid-19 world pandemic, this scenario was inspired to test a campus plaza with the government recommended social distancing guidelines in its open space. Figure 7 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 is 2 meters from another individual. The dimensions of the pod sizes can be tested utilizing parametric technology to evaluate the human experience during a contagion pandemic.

To generate dimensions to the Voronoi pods, the Grasshopper script must be manipulated to accommodate these changes. Expanding off this idea, 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. In this scenario, the diameter of each Voronoi cell is approximately 2m wide, pursuant to the social distancing guidelines.

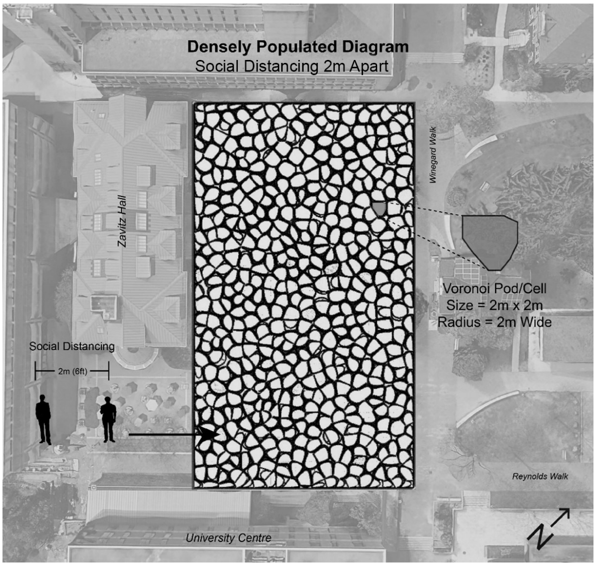

Fig. 7:
The Illustration by the students displays a Voronoi diagram testing for 'social distancing'. The size for each Voronoi pod/cell is 2m by 2m wide. This safe measurement is considered the social distancing 'safe distance' for individuals to be around each other.

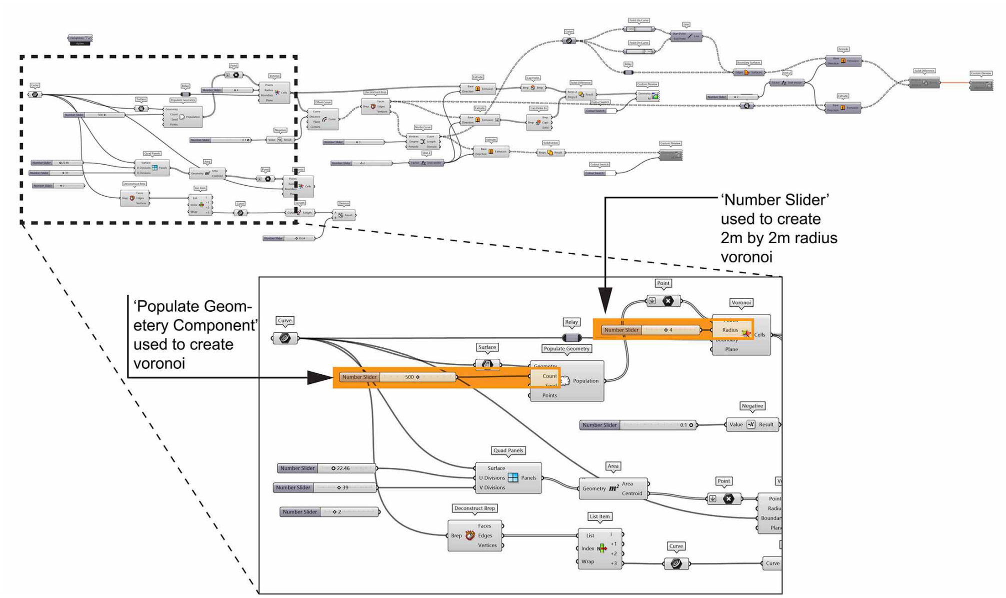

Fig. 8: Grasshopper script displaying the specific components used to generate Voronoi pods/cells sized at 2m by 2m. The highlighted 'Number Slider' is used to define the maximum diameter for each cell which then will be optimized to create the 2m by 2m Voronoi cells.

4.2 Grid Voronoi System and Line Attractor Tool

This algorithm integrates an attractor line tool to provide a dynamic Voronoi gird geometry based on a manually defined path created in the 3D model environment. Attractor lines attract or repel other objects, similar to virtual magnets. Attractors can influence any number of parameters of surrounding objects, including scale, rotation, color, and position. These parameters are changed based on their relationship to the attractor geometry. In this generative algorithm, the attractor line changes the Voronoi pods' geometries based on the proximity to the attractor line. The student was able to create multiple spatial scenarios by just drawing and changing desired paths in the test site (Figure 10). The instantaneous execution of the algorithm and the corresponding change in the 3D model helped the student contemplate multiple design alternatives.

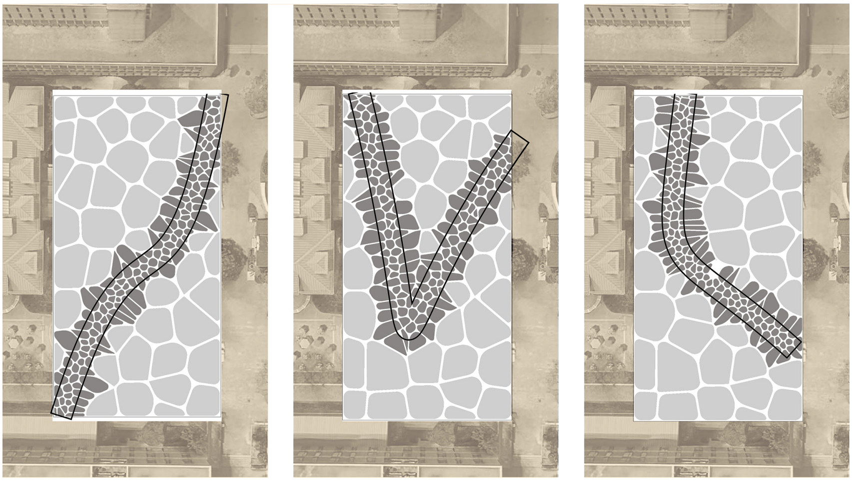

Fig. 9: Concept design iterations using a generative algorithm by a novice student

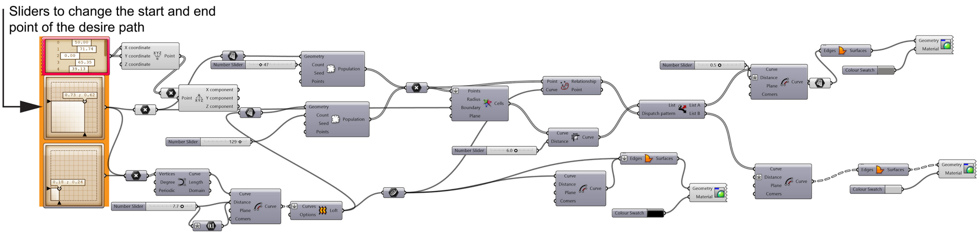

Fig. 10: Grasshopper Script to generate design scenarios by changing the desired path

4.3 Path Finding Tool

Inspired by Flowing Garden and Fletched Park circulation systems, a generative algorithm was designed by the research team to test the ability of parametric technology for modelling pathfinding and pedestrian circulation. The purpose of this test was to evaluate how an experimental approach can identify the shortest and most efficient pedestrian routes throughout the local campus plaza. Figure 9 displays illustrations of a digitally generated grid system overlaying the site's boundary with the similar Voronoi pattern used in the previous spatial analysis. Using the Voronoi pattern for path routes can aid in avoiding obstacles on site while also determining the most optimal route. The grids shown in Figure 11 were generated using a script where a 'pathfinding' component was applied. 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, '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 as 'set points' within the script, a pathway is identified for an individual to navigate and displays the route using the shortest most efficient path possible. Consequently, 'point A' and 'point B' can be set to any attractor point throughout the site, however this can only be applied using the Grasshopper script. Therefore, the most efficient route can be determined regardless of where an individual is standing on a site.

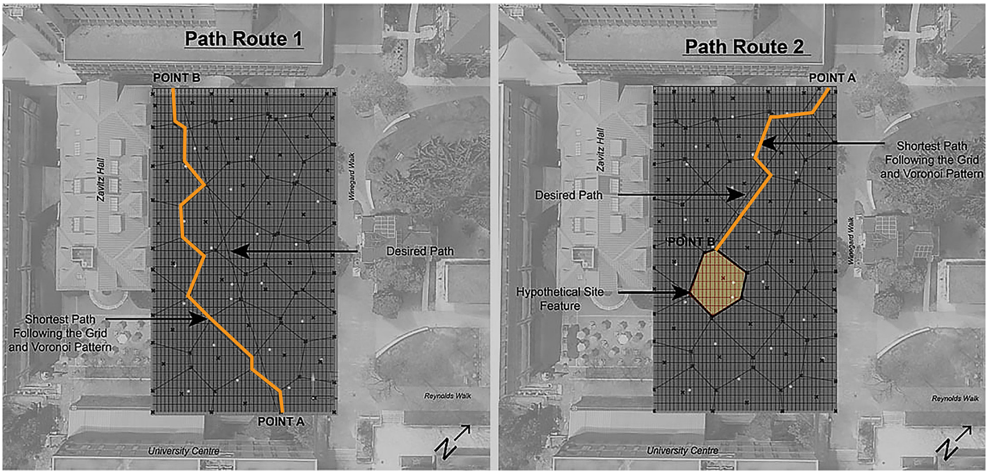

Fig. 11: The student used Rhinoceros3D and Grasshopper plug-in software's for determining the shortest most efficient pedestrian routes at a local campus

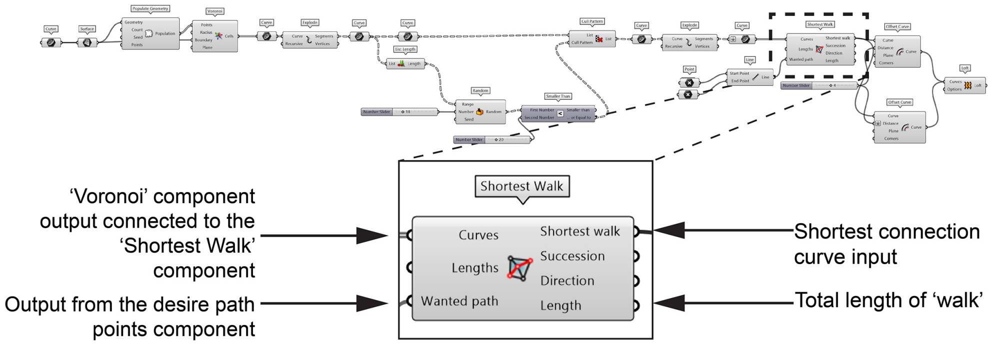

Fig. 12: This illustration provides an overview of the 'grid' and 'Voronoi' components in the Grasshopper script used to generate the pathfinding approach of identifying the shortest most efficient pedestrian routes on a campus plaza

4.4 Results

The three simplified generative algorithms could generate fairly complex design and analysis outcomes for a novice student with no knowledge of parametric software programs. Compared to traditional 3D modelling, the concept design iterations were conducted in a shorter amount of time. This experimental design technique can benefit both students and designers in the future, as it can save time, ensure designed spaces can continue to be sustained and remain responsive to a variety of circumstances, and lowering the likelihood of errors. In turn, this approach allows for design efficiency while still controlling creativity.

5 Discussion

Research suggests that there is a gap between skills, training, application of knowledge and utilizing the technology for parametric design (SCHNABEL 2007). This gap is not only in the academic studio environment, but also within landscape architecture practice as well. With technical and cultural interactions between humans and computers growing exponentially, technologies such as parametric design allow professionals to create solutions beyond traditional analogue design approaches. Learning this method may be an initial obstacle for some users; however, this should not hinder this method's ability to produce long-lasting and efficient landscape designs. To overcome this knowledge gap, there needs to be a curriculum review and a minor shift of focus in pedagogy systems in universities. All professions, including those within the field of landscape architecture, must expand their skills to address the complex set of modern issues facing humans, including climate change. The expansion of skills could be implemented by encouraging students to use basic parametric design scripts in their projects. These simple scripts can promote an interest in parametric design in the field of landscape architecture.

6 Conclusion and Outlook

Key influential figures in landscape architectural practice and academia continue to explore and push the envelope in digital landscape architecture design. For example, Jose Alfredo Ramirez, the co-director of the Landscape Urbanism program at the Architectural Association and the director of Groundlab, and Chris Reed, Professor of Practice at the GSD and founder of Stoss Landscape Urbanism, are implementing generative design in their studio courses and setting the stage for future landscape architects. This introduction in the studio courses encourages this parametric skills-building. Students can apply these skills not only for pattern making and form making in the design but apply parametric design to help with other landscape issues, including climate change related to landscape design. Ramirez and Reed are training students to explore creative measures with generative algorithms and provide complex geometries, data-driven analyses, form modelling and analyses, algorithmic-based compositions, and optimization.

Universities and educational institutions can make a significant contribution in filling this gap by training future landscape architects. It is expected that these skilled professional practitioners and researchers will be introduced to the community and improve the model of practice-based research, which ultimately enhances the quality of spaces designed by landscape architects.

References

AMOROSO, N. (2012), Digital Landscape Architecture Now. New York, Thames & Hudson Inc.

AUTODESK (2019), Generative Urban Design: A Collaboration Between Autodesk Research and Van Wijnen. https://www.autodesk.com/autodesk-university/article/Generative-Urban-Design-Collaboration-Between-Autodesk-Research-and-Van-Wijnen-2019 (March 22, 2022).

BONAFEDE, M., E. (2014), Plasma Studio: From Topological Geometries to Landscape Urbanism. Edil Stampa, Roma.

CANTRELL, B. & MEKIES, A. (2018), Codify: Parametric and Computational Design in Landscape Architecture. Abingdon, OX and New York, NY, Taylor & Francis Group, Routledge

CAETANO, I., SANTOS, L. & LEITAO, A. (2019), Computational design in architecture: Defining parametric, generative, and algorithmic design. Frontiers of Architectural Research, https://doi.org/10.1016/j.foar.2019.12.008.

FARNSWORTH, D., GALLO, R., WIEST, J. & JO, Y. (2020), Little Island: Sculptural Structure through Digital Design and Fabrication. In: BURRY, J., SABIN, J., SHEIL, B. & SKAVARA, M. (Eds.), Making Resilient Architecture. UCL Press, London, UK, 294-302.

FLETCHER STUDIO (2018), About. https://www.fletcher.studio/about (March 22, 2022).

FLETCHER STUDIO (2021), Project: South Park. https://www.fletcher.studio/southpark (March 22, 2022).

GRANADERIO, V., PINA, L., DURATE, P. J., CORREIA, R. J. & LEAL, M. S. V. (2013), A general indirect representation for optimization of generative design systems by genetic algorithms: Application to a shape grammar-based design system. Automation in Construction, 35. https://doi.org/10.1016/j.autcon.2013.05.012.

GROUNDHOG (2017), South Park. https://groundhog.la/projects/south-park/ (March 22, 2022).

GROUNDLAB (2020), Our Works. http://groundlab.org/ (March 22, 2022).

HEATHERWICK STUDIO (2021), About. http://www.heatherwick.com/studio/about/ (March 22, 2022).

MNLA (2021), Little Island. https://www.mnlandscape.com/projects/Pier_55 (March 22, 2022).

PIRLO, G. & IMPEDOVO, D. (2012), Voronoi-Based Zoning Design by Multi-objective Genetic Optimization. IAPR International Workshop on Document Analysis Systems, 10. https://ieeexplore-ieeeorg.subzero.lib.uoguelph.ca/stamp/stamp.jsp?tp=&arnumber=6195367 (March 22, 2022).

SCHNABEL, A. M. (2007), Parametric Designing in Architecture. Computer-Aided Architectural Design Futures (CAAD Futures), 237-250. https://link.springer.com/chapter/10.1007/978-1-4020-6528-6_18 (March 22, 2022).

WALLIS, J. & RAHMANN, H. (2016), Landscape Architecture and Digital Technologies: Reconceptualising design and making (1st Ed.). Routledge, New York, NY.